AN INVESTIGATION OF THE POTENTIAL FOR THE USE OF ORGANIC FERTILIZER ON SMALL, MIXED FARMS IN COSTA RICA

BY

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Two types of aerobic, thermophilic compost were produced in Costa Rica, one enriched in superphosphate and one unenriched. Three study sites, ranging from a seasonally very dry to a very humid climatic regime, were selected for the study in order to examine the feasibility of producing compost under this range of tropical environmental conditions. Zones where cattle, especially dairy cattle, are important or apt to become important were selected because of the need to minimize labor costs for collecting manure. Only manure from corrals or milking parlors was used. A very simple composting technique was employed, incorporating manure and crop residues in an overground heap.

Results show that the simple overground heap is not adequate for compost production under the very humid conditions encountered. High levels of nutrient loss, especially nitrogen loss, occurred, and near anaerobic conditions prevailed in the heaps on occasion. Where soils are high in heavy metals, these elements accumulated

at high levels in the compost as well. At less humid sites, the technology proved adequate.

The compost was used as a fertilizer for corn production at all three sites. Five fertilizer treatments were employed: unenriched organic, enriched organic, combined chemical and organic, chemical, and a control receiving no fertilization. Organically treated plots received only one fertilizer application while the chemically treated plots received two. Corn grain yields at two of the three sites did not differ significantly (0.05 significance level) on the chemically and organically treated plots, indicating that the organic fertilizer is as effective as chemical or combined chemical and organic fertilizer for corn production.

Labor costs were calculated for producing the compost and show that the cost of 1 kg of plant nutrients (n, P_2O_5, K_2O) is comparable in chemical and organic fertilizer as of January, 1981. A survey of farms in three zones showed that the overall feasibility of using compost varies greatly from zone to zone, depending on such factors as the number of cattle maintained on the farm, the frequency of milking, availability of easily collected vegetative material, availability of a mechanical chopper, and the presence of high value crops on the same farm.

CHAPTER I
INTRODUCTION

Concern over an imbalance between food production capability and the world's growing human population has been voiced for many years. In the post-World War II period, and particularly in the 1960's and 1970's, predictions of coming disastrous food shortages were widely expressed (Borgstrom, 1965; Erhlich, 1968; Meadows et al., 1972; Mesarovic and Pestel, 1974). Others (Cole et al., 1973; Poleman, 1975; Wortman, 1976) argued just as vehemently that world food production could keep pace with population growth.

Whatever the validity of the opposing viewpoints, the entire post-war debate has served to focus the attention of the international scientific community on the need to increase agricultural productivity, particularly in developing nations. As a result, as early as 1960 the International Rice Research Institute (IRRI) was established in the Philippines (Jennings, 1976). Its success and that of the International Center for the Improvement of Maize and Wheat (CIMMYT), established in Mexico in 1966 (Jennings, 1976), in breeding and introducing the use of improved grain varieties have led to the establishment of an extensive international network of agricultural centers (Wade, 1975).

While the success of these centers in reaching their stated goals has not been uniform, real gains have been made. The Food and Agricultural Organization of the United Nations (FAO) shows that total food production in all developing countries increased an

average of 3.0% per year for the period 1961-70, and 2.8% per year for the period 1970-77 (FAO, 1978). Such growth rates are excellent, but their impact on alleviating hunger is often limited by simultaneous population growth. Thus, in the period 1961-70, the average annual increase in per capita food production was only 0.6% for all developing countries, and was only 0.5% in the period 1970-77 (FAO, 1978).

It is not possible to assess the degree to which increases in food production have been due to the efforts of the international research centers in particular, and to the concerted efforts of the international scientific community in general, to address the problem of raising food production in developing countries, and especially in the humid tropics. Nonetheless, it is clear that intensification of agricultural practices is a key to increasing world food supplies, although, of course, expansion of agricultural land is possible in some areas.

Cost and Availability of Needed Inputs

As Hopper (1976) correctly notes, success in intensifying agricultural production through the use of high-yielding varieties requires access to supplies of fertilizer and abundant water. Due to loss of native soil fertility, and to maintain soil resources for the future, fertilizer should be used even where traditional varieties are planted. It is essential that farmers, especially the millions of small farmers who make up the bulk of the farming population in most countries, be assured access to abundant, timely, and low-cost supplies of fertilizer if they are to continue the

progress that they have been making in raising yields. In fact, since small farmers have often benefitted less from the introduction of new technology than larger farmers (Chambers and Farmer, 1977; Perelman, 1976), even greater efforts must be made to make sure that small farmers have access to needed inputs. Otherwise, the net outcome of introducing more intensive agricultural technology may be to increase food production at the cost of social imbalance resulting from displacement of small farmers who cannot compete successfully for the needed inputs.

The high dependence of intensive agriculture on these inputs, such as herbicide, pesticide, diesel, and particularly fertilizer, is cause for alarm. Both the cost and the availability of these materials are now bringing into question the feasibility of increasing, or perhaps even maintaining, current levels of use on the world's small farms. In addition, as Hopper (1976) mentions, the risk to the family on small farms when cash indebtedness in incurred is so great that many small farmers are reluctant to use purchased inputs even when they are available at relatively low cost.

The major problem in the foreseeable future is not so much that of absolute scarcity of fertilizer as it is the rising cost and relative scarcity of fertilizers in developing countries. All fertilizer production, and particularly industrial nitrogen fixation, is tied to the cost of energy. Within the United States, and not taking into account any transportation costs for either raw materials or finished products, production of ammonium nitrate prills requires about 50 million BTU per ton of nitrogen (Davis and Blouin, 1977).

Although energy costs are lower for phosphorus and potassium, 8 million BTU per ton of phosphate (P_2O_5) in triple superphosphate and 4 million BTU per ton of potash (K_2O) to mine and process fertilizer grade potassium chloride (Davis and Blouin, 1977), rising energy costs are still strongly reflected in their market price.[1] In 1975, fuels and electric power constituted only about 12% of the cost of fertilizer manufacture in the United States (Sherff, 1975). However, the relative contribution of energy costs to total fertilizer production costs has been high and will increase greatly. This occurs both because energy costs are rising rapidly in proportion to other costs and because of the dependence of industrial nitrogen fixation on a single energy source, natural gas, that is in absolute shortage both in the United States and worldwide (Sherff, 1975).

In the developing countries the cost of fertilizers is even more adversely affected by rising energy costs. Many developing nations must import all the raw materials to make fertilizers, or import fertilizer itself. Not only does the cost of the raw materials themselves rise, but so do costs associated with transportation of raw materials. Internally, the cost of distributing the finishes product also rises in direct proportion to rising petroleum costs, especially in those nations that must import their gasoline and diesel fuel. For developing countries, then, the impact of rising

[1]Other authors indicate much higher energy costs. Sherff (1975) estimates 62 million BTU per ton nitrogen in prilled ammonium nitrate, 19 million BTU per ton P_2O_5 in superphosphate, and 6 million BTU per ton K_2O in potassium chloride, for example.

energy costs on fertilizer prices is both more complex and greater than it is in developed nations which have their own raw materials and energy sources, especially natural gas.

Agriculture accounts for a small percentage of total commercial energy use in both developing and developed countries, 4.0% in the former and 3.4% in the latter (Mudahar and Hignett, 1981). Although a relatively large portion of this energy use is in the form of fertilizer in developed countries, about 33% (Price, 1981), fuel and materials for machinery far outweight fertilizer in energy inputs in agriculture. In developing countries, where fewer energy inputs are used, fertilizer accounts for a much higher percentage of agricultural energy inputs, projected at 70.3% by 1985-86 (Stout et al., 1979). The impact of rising energy costs on fertilizer prices is therefore relatively much more important in overall increasing costs of production in developing than in developed countries.

All of these factors came into play during the 1973-74 energy crisis. Anjos and Noronha (1974) have analyzed the effects of the energy crisis and an accompanying cyclical shortage of all major fertilizers that occurred in 1973-74 on fertilizer costs and supplies in Brazil. Using 1967 as a base year with fertilizer prices in both North America and Brazil at 100%, prices of fertilizer for North American farmers reached slightly over 160% of their 1967 value in June, 1974. In Brazil, prices reached 200% of the 1967 value (Anjos and Noronha, 1974). This reflects the absolutely higher cost of fertilizer in Brazil and also indicates that supplying nations give preferential treatment to their own internal markets in time of

crisis, which provokes both speculative price increases in importing countries and relatively more severe shortages.

Harriss (1977) also discusses the problems that developing nations, which are heavily dependent on imported fertilizers, face in times of crisis. In North Arcot District, India, in 1974, a black market in fertilizer developed as a response to government controls on price and distribution. Black market prices, which are normally some 30 to 50% higher than controlled prices, rose to 150% of controlled prices during the oil crisis (Harriss, 1977). In addition, the shortages caused severe misallocation of the resource and resulting losses in yields in undersupplied areas.

These, and other similar cases that could be cited, illustrate the need for developing countries to achieve some degree of self-sufficiency in fertilizer supplies. Clearly, the problems associated with dependence on imported fertilizers manifest themselves most acutely in times of crisis, such as occurred in the 1973-74 oil embargo. There are, however, more general long-term problems associated with over-dependence on external sources of agricultural inputs as well. As Dahlberg (1979) points out, developing nations can easily become so reliant on externally supplied sources of inputs that their food producing capacity meets severe constraints that are imposed by institutions and events beyond their own control. Since these countries, with weakened economies, will be least able to compete in the international marketplace for scarce resources, it is important that long-term trends be carefully evaluated so that appropriate strategies for the future can be developed.

One important aspect of a viable strategy is to augment the capacity of developing nations to produce their own chemical fertilizer. Many countries have constructed production facilities in recent years, and Food and Agriculture Organization analyses indicate that developing countries will reach the target figure of 25% of world chemical fertilizer production by the year 2000 (FAO, 1978). Still, most developing nations will not have the necessary resource capability to develop an adequate national fertilizer industry. Nonetheless, substantial imports will still be necessary to meet projected demand, and where raw materials are not available locally, dependence on external sources of fertilizer will continue. Further, several authors (Shapley, 1977; Tanner, 1968; White-Stevens, 1977) have made estimates of total fertilizer demand in the year 2000 and beyond, based on both desired levels of use and extrapolation of past trends in fertilizer use. Whatever method used, it is clear that, at some point, total demand will outstrip world production capacity of chemical fertilizer.

Alternatives for Improving Fertilizer Use and Efficiency

From both short-term and long term points of view, it is important that developing nations, and in fact, all nations, increase efficiency of fertilizer use and begin to search for sources of fertilizer other than chemical fertilizer. Research that can provide farmers with more efficient methods of fertilizer use are important, as are efforts to breed better nitrogen-fixing strains of plants and encourage their use. Yet, even readily available sources of fertilizer have often been ignored, both in developing and industrialized

nations, in the post-World War II period as chemical fertilizers became abundantly available and relatively inexpensive.

Human and animal wastes are supplementary sources of fertilizer that all too frequently go unused. These sources have the advantages of being available on the farm at little or no cost to the farmer, and without the added cost of transportation either to the country or to the farm, with perhaps the exception of some transportation on the farm itself. While their use could almost certainly not completely replace the use of chemical fertilizers, they could provide an important supplementary source of fertilizer. Failure to utilize these resources is unfortunate from another point of view as well, since the accumulation of such materials pose increasing health and pollution hazards in both industrialized and developing nations.

The fertilizer value of these materials is great. Using production figures based on an extrapolation of Indian findings, van Voorhoeve estimates that human wastes, cattle wastes, and farm compost produced 12.25 million metric tons of nitrogen, 2.87 million metric tons of phosphorus, and 2.61 million metric tons of potassium in developing nations in 1971, for a total of 17.73 million metric tons (Duncan, 1975).[2] In the same year, 13.2 million metric tons of nitogen, phosphorus, and potassium from chemical fertilizer sources were used in those countries (Singh, 1975).[3] While these figures

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[2]Van Voorhoeve's data are reproduced in Duncan's article. The original source is J. J. C. van Voorhoeve, "Organic Fertilizers: Problems and Potential for Developing Countries," World Bank Fertilizer Study, Background Paper No. 4, I. F. C. Office of the Economic Adviser, 1974. Van Voorhoeve's calculations exclude Central America and Oceania.

[3]Singh draws his figures from the 1971 FAO Production Yearbook.

are only estimates, they do show that the nutrients available in human and animal wastes in 1971 exceeded those applied in chemical fertilizers in developing nations.

Makhijani and Poole (1975) estimate that in September, 1974, fertilizer dollar values were $400 per ton of nitrogen content, based on the price of urea with 46% nitrogen content; $240 per ton of phosphorus, based on superphosphate with 56% P_2O_5 content; and $150 per ton of potassium, based on potash with 60% K_2O content. At these prices, the dollar value of the nitrogen, phosphorus, and potassium contained in the human and animal wastes produced in developing nations in 1971 was $4,900 million for nitrogen, $718 million for phosphorus, and $392 million for potassium. Further, these values are probably underestimates since farmers in the United States, the source of Makhijani and Poole's base prices, typically pay less for fertilizer than those in developing nations.

Organic fertilizers have played an important role in agriculture in many parts of the world, but despite the importance of such fertilizers in many agricultural systems, little attention has been devoted to their use in recent years. In some areas animal wastes are simply not readily available. Such is the case in large areas of Africa where the tsetse fly prevents much animal husbandry. In other areas, animals are an important element in agriculture, but are not integrated into the farming system in such a way that their wastes are reclaimed. Effective utilization of animal manures requires penning or tethering and may therefore require change in agricultural customs, but several writers comment on the failure to utilize cattle manure

in Uganda, for example, even though the animals are tethered (Cleave and Jones, 1970; Parsons, 1970). The use of human excreta poses additional problems both in the evolution of an appropriate system of collection and re-distribution, as well as the development of socio-cultural attitudes that endorse its effective utilization.

CHAPTER II
PROJECT OBJECTIVES, BACKGROUND, AND STUDY SITE SELECTION

This research was undertaken to examine the socio-economic and environmental constraints on the use of composted animal manure on small farms in Costa Rica. The study was integrative in nature, that is, all facets of manure utilization, including the problems associated with compost production, yield response of corn upon application, effects on selected soil chemical properties, and integration into overall farm labor availability, were considered. The full research program, described below, was completed at three study sites, offering a variety of socio-economic, physical, and biological settings for comparison.

Specifically, the project objectives were

(1) To determine the quality of compost that can be produced using the simplest possible technology under the variety of environments encountered;

(2) to compare the quality of two types of aerobic, thermophilic compost, one enriched in phosphorus and the other not;

(3) to compare the yield of corn using a single application of compost or compost combined with chemical fertilizer to yields obtained where no fertilizer was used, or where two applications of chemical fertilizer were made;

(4) to determine the labor and material requirements for making and applying compost;

(5) to examine the effects of compost on selected soil chemical

properties; and

(5) to determine the possibilities for using compost in the three zones in Costa Rica in terms of both labor requirements and availability of needed resources.

The study was integrative in two senses. The research sought a method for combining animal and crop production so that the small farmer could reap the greatest benefits from his mixed farming system, where both components are generally present. Further, both the physico-biological and socio-economic environments of the small farmer were taken into consideration. Overall, it is the combination of all project objectives, rather than any single facet of the study, which yields insights into the possibility of putting this technological innovation into practice.

It is useful to examine current trends in fertilizer use in Costa Rica in order to put the objectives of the project in proper perspective. The following brief discussion describes the fertilizer industry in Costa Rica and examines current trends in fertilizer use and costs in the country.

Fertilizer Production in Costa Rica

Like many developing nations, Costa Rica has developed a fertilizer industry, and both the government as a whole and the Ministry of Agriculture strongly encourage the use of fertilizer. The first fertilizer plant in Costa Rica was established in Puntarenas by Fertilizantes de Centroamerica S.A. (FERTICA) in 1963 (Organization of American States, 1970). While FERTICA was originally privately owned, it is now a public corporation. The Refinadora Costarricense

de Petroleo (RECOPE) bought 10% interest in FERTICA in January, 1978, and the Corporación para el Desarrollo S.A. (CODESA) bought 90% interest in March, 1980. Both organizations are funded by the Costa Rican government (Ortiz, 1981). FERTICA imports, processes, and mixes fertilizer raw materials and distributes and sells fertilizer in Costa Rica. Part of its production is re-exported to other Central American nations as well.

While FERTICA accounts for about 70% of all fertilizer sales in Costa Rica (Ortiz, 1981), six other private companies also market fertilizer products in the country. They are Distribuidora Superior S.A., Holterman and Petchel Ltda., Abonos Agro S.A., Rainbow Ltda., Casa del Agricultor Ltda., and J. H. Baker and Bro., Inc. Some of them own mixing plants in Costa Rica as well (Organization of American States, 1970). In addition, banana growers import some fertilizer directly, especially urea, although they buy most of their fertilizer on contract from FERTICA.

Fertilizer sales and distribution are not government controlled in Costa Rica. Both individuals and intermediaries may buy fertilizer from FERTICA at any of its three warehouses in Puntarenas, Alajuela, or Liberia. Cost of transportation from the Puntarenas plant, averaging $US 0.54 per 100-lb bag, to the other two warehouses is split evenly between FERTICA and the customer.[4] Further

[4]All conversions from the Colon to the U.S. dollar will be made on the basis of ¢8.54 per $US 1.00. This exchange rate is no longer applicable, but the current rate changes frequently. The old rate was effective until November, 1980, and local prices, especially labor costs, did not yet reflect, for the most part, the new, higher rates when this research was completed.

transportation costs are the client's responsibility (Ortiz, 1981).

FERTICA imports all raw materials for its fertilizer production. These include sulfur, ammonia, urea, potassium sulfate, potassium chloride, diphosphate, triple superphosphate, phorphoric rock, and minor elements. Canada is the chief supplier of potassium chloride, but Mexico and the United States supply most other materials. These materials, most importantly triple superphosphate, are not resold as single element fertilizer except in very small quantities because there exists a tax on all primary materials which are not processed within the country (Ortiz, 1981). Almost all fertilizers,with the exception of some forms of nitrogen fertilizer, are available only in complete mix formulas. It is difficult and expensive to procure superphosphate, except in complete mixes, of particular importance because of phosphorus deficiency in many Costa Rican soils.

Fertilizer Use and Cost in Costa Rica

As Pritchett and Blue (1966) point out, although certain Costa Rican export crops, such as coffee and bananas, have been fertilized for many years, use of chemical fertilizers in Costa Rica is relatively recent for most farmers and for most crops. As Table 1 shows, imports of fertilizer materials have increased greatly for the period of record, with extremely rapid increases occurring since 1950. Since 1963, when FERTICA began to export fertilizer,[5] all of these materials have not been consumed in Costa Rica. Nonetheless, the growth in demand does indicate that fertilizer use has increased

[5]FERTICA exported 42,467 metric tons of fertilizer in 1965, 32,438 tons in 1970, and 70,200 tons in 1974 (Ministerio de Agricultura, 1974).

Table 1. Fertilizer imports and costs in Costa Rica, 1920-74.

Year	Total Imports (Metric Tons)	Total Cost (Thousands, $US)	Cost/Ton ($US)
1920	272	24	88
1925	1,409	152	108
1930	1,591	195	123
1935	2,462	340	138
1940	5,808	284	49
1945	3,508	193	55
1950	15,802	1,454	92
1955	24,208	2,413	100
1960	57,780	4,866	84
1965	169,528	11,745	69
1970	139,217	7,497	54
1974	168,900	31,900	189

Source: Ministerio de Agricultura, Consejo Agropecuário Nacional, Comisión de Fertilizantes. 1974. Informe Sobre el Consumo de Fertilizantes en Costa Rica. Preliminar. San Jose: Ministerio de Acricultura.

greatly in the post-World War II period. The Ministry of Agriculture (1974) reports, for example, that fertilizer use grew by 7.7% per year for the period 1963-73. Table 1 also gives some indication of the cost of these materials to Costa Rica.

Table 2 indicates fertilizer use on basic grains, pasture, the most important export crops, and vegetables. With the exception of vegetables, a high value crop grown for sale in San Jose, fertilizer use on export crops greatly exceeds that on crops grown for domestic consumption and pasture. Two crops alone, coffee and bananas, accounted for 60% of all fertilizer use in 1980, whereas the basic grains accounted for only 12% of all fertilizer consumption. Similarly, the table shows that application rates on corn, rice, beans, and pasture remain low, especially in comparison to use on export crops.

Despite the imbalance suggested by these data, fertilizer use on basic food crops has grown in the past. In 1963, only 33% of all land planted in rice and virtually none of the land planted in corn and beans were fertilized (Pritchett and Blue, 1966).[6] At roughly the same time, in 1965, corn, rice, and beans accounted for only 4% of all fertilizer consumed, whereas coffee, bananas, and sugar cane accounted for 85% of all fertilizer use. By only 1970, some 12% of all fertilizer consumed in Costa Rica went to corn, beans, and rice, and use on the three export crops had dropped to 71% (Ministerio de Agricultura, 1974), and by 1973, 63% of all land

[6]Based on 1963 census data.

Table 2. Fertilizer use by crop, in Costa Rica, 1980[a]

Crop	kg/ha	% of All Fertilizer Used
Banana	1,150	20
Coffee	779	40
Sugar Cane	320	10
Beans	120	2
Corn	202	3
Rice	200	7
Pasture	158	2
Vegetables	1,207	2

[a]These preliminary data were compiled in early 1981 and some minor changes may appear in final data.

Source: Fertilizantes de Centroamérica S.A. 1981a. Consumo Nacional de Fertilizantes y Area Fertilizada (por Cultivo). Mimeo Sheet. San José: FERTICA.

in rice, 20% of all land in corn, and a small percent of all land in beans were fertilized (Ministerio de Economica, 1974).

Since 1970, however, relatively little progress has been made. As Table 2 indicates, in 1980, the export crops still accounted for 70% of all fertilizer use, and rice, beans, and corn for only 12%. The increase in fertilizer consumption, from 65.2 metric tons in 1965, to 114.1 metric tons in 1970, to 162.5 metric tons in 1980, has not changed the basic trends in fertilizer use (FERTICA, 1981b; Ministerio de Agricultura, 1974). These data illustrate that farmers can best afford to fertilize the low risk, high value crops, especially those grown for export. Fertilizing basic food crops grown for domestic consumption remains problematic. These tendencies will be exaggerated as fertilizer prices rise, and show the need for developing a low-cost, readily available source of fertilizer.

Table 3 illustrates the use of fertilizer on small (20 ha or less) versus large farms. The willingness of farmers with small acreages to use fertilizer when a high value crop can be grown is demonstrated by the data for fertilizer use on vegetables, a very high value crop. The vast majority of vegetables are grown on small farms near the capital, in the provinces of San José, Alajuela, and Cartago. As the data in Table 3 show, these small farms account for a similarly high percentage of the fertilized land planted in vegetables, with fertilizer application rates exceeding those on large farms. Small farms also have a higher fertilizer application rate on pasture than do large farms. Again, this is explained by the high fertilizer use on small dairy farms near the Central Valley producing milk for sale in San Jose.

Table 3. Fertilizer use on large versus small farms, in Costa Rica, by crop, 1973.

Crop	20 ha or Less			More Than 20 ha		
	% of All Land Planted in Crop	% of All Fertilized Land Planted in Crop	Fertilizer Applied (kg/ha)	% of All Land Planted in Crop	% of All Fertilized Land Planted in Crop	Fertilizer Applied (kg/ha)
Coffee	49	40	554	51	61	705
Banana	4	Less Than 1	220	96	100	1,301
Sugar Cane	22	15	399	78	85	445
Corn	38	48	183	62	52	163
Rice	15	9	162	85	91	223
Vegetables	49	62	1,164	41	38	1,042

Source: Ministerio de Economía, Industria y Comercio, Dirección General de Estadística y Censos. 1974. Censos Nacionales de 1973. Agropecuário. Vol. 3. San José: Ministerio de Economía, Industria y Comercio.

In general, however, small farms account for a smaller percentage of the fertilized acreage than they do of the total acreage planted in a given crop, and they generally exhibit lower application rates. These data show that small farmers are well aware of the advantages that are gained when fertilizer is applied and are willing to use fertilizer when risk is low and it is cost effective to do so.

The problem now confronting Costa Rican farmers is that of rapidly rising fertilizer costs. In Costa Rica, as elsewhere, fertilizer prices fell and stabilized after the severe increases in 1973-74. This occurred both because the oil embargo ended and because the worldwide shortfall in fertilizer production that took place at the same time was eliminated as new production facilities were built. In the last two and one-half years, however, fertilizer prices have begun to rise once again.

Figure 1 shows the cost of three commonly used fertilizers in Costa Rica for the period 1977-80. The graph illustrates the average price in the entire country, although there are regional variations due to transportation costs. The trend toward higher prices that began in 1979 shows no sign of abatement. In fact, between December, 1980, and January, 1981, the cost of these three fertilizers rose another 7.7% (Ministerio de Agricultura, 1981a), and again, between January, 1981, and March, 1981, another 8% increase occurred (FERTICA, 1981b). Further price increases can be expected as a result of both generally increasing worldwide fertilizer prices and because of the inflation currently plaguing the Costa Rican economy.

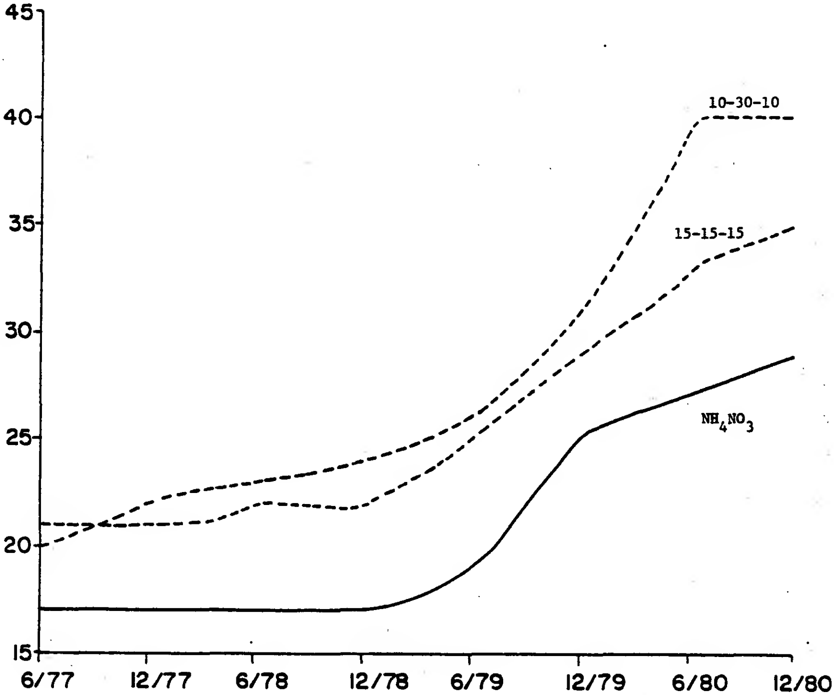


Fig. 1. Cost of three commonly used fertilizers in Costa Rica.

These trends clearly demonstrate the need to seek alternative sources of fertilizer in Costa Rica. Even discounting short-term price fluctuations that may occur, no fertilizer raw material is produced within the country. Thus, the long-term prospect is one of continued dependence on external sources.

Study Site Selection

The study was conducted in Costa Rica for a number of reasons. First, the country offers a wide variety of climatic zones in relatively close proximity. Given the well developed transportation system in most of the country, this makes it possible to conduct research under a variety of environmental conditions simultaneously. Second, the Centro Agronómico Tropical de Investigación y Enseñanza (CATIE) expressed interest in the project and offered the use of their facilities in the Department of Animal Production. Two projects under investigation were of particular interest: one concerned with the use of crop residues, a possible use being raw material for composting; and another designed to increase milk production on small farms, where fertilizer could be a key element (CATIE, 1978; 1980a).

Finally, the project was undertaken in Costa Rica because the use of organics as fertilizers is not traditional and has received little attention. Large animals are a post-Columbian introduction in Latin America and it is not surprising that pre-Columbian use of animal manure was very limited. Winterhalder, Larsen, and Thomas (1979) report that use of manure, traditionally llama dung and more recently cattle and sheep manure as well, is practiced in highland

Peru. Similarly, Vargas (1942) describes manure use by pre-Columbian peoples in Mexico. There is no strong tradition of integrated animal and plant production in Latin America such as characterizes much of Southeast Asia.

Some interest in using organic fertilizer prior to the widespread availability of chemical fertilizers after World War II had been expressed. In Puerto Rico, projects were undertaken to promote the utilization of organics, for example (Perez-Garcia, 1948). In the post-World War II period, interest was minimal, but recently has come to the fore again in some areas. Brazil has begun to compost municipal wastes in São Paulo (Burnett, 1975), and Peace Corps volunteers in San Carlos, Costa Rica, worked with the use of municipal wastes (Sullivan, 1975). In total, however, very little research has been undertaken. The recent series of publications by the Food and Agricultural Organization (1975, 1976, 1977, 1978a) does not describe the use of organic wastes in Latin America although its coverage for Africa and Asia is excellent. Given the rising cost of fertilizer not only in Costa Rica but throughout Latin America, the ongoing dependence on foreign sources of chemical fertilizer for Costa Rica, and the ready availability of animal manure, especially cow manure, on many small farms in the country, the use of organics deserves attention.

Within Costa Rica, the full research program was completed at three study sites: Cariari in the Province of Limon; Turrialba in the Province of Cartago; and Cañas in the Province of Guanacaste. Compost was also made and applied in Santa Elena in the Province of

Puntarenas. However, by the time interest in using compost developed there it was not possible to carry out the full research program. Farmers in Santa Elena were interviewed, and these data are included here, but compost trials and field test plots were not established. The study sites were chosen on the basis of the differences they display both in environment and farming systems, and to accompany other CATIE research projects. A brief description of each follows.

Although manure is a carefully husbanded resource in some places, such as India and China (King, 1911; Makhijani and Poole, 1975), and is carefully collected even from unpenned animals, this is not the case in Costa Rica. Further, labor is often in short supply on small farms and it is always relatively expensive to hire off-farm workers. As a result of these factors, it is most feasible to use the manure of penned or tethered animals, which is easily collected. One major source of manure, therefore, is that left in milking parlors or corrals while cows are milked, and for this reason research was conducted on dairy farms.

Turrialba

Turrialba is situated 639 m above sea level in a valley on the eastern flank of Costa Rica's Cordillera Central (see Fig. 2). For the period of record 1961-78, the mean annual temperature was 21.6°C, with a mean low temperature of 17.7°C and a mean high of 26.7°C (Instituto Meterológico Nacional, 1979c). The coolest month is January, with a mean temperature of 20.4°C, and the warmest is May, with 22.4°C mean temperature (Table 4). Precipitation averages

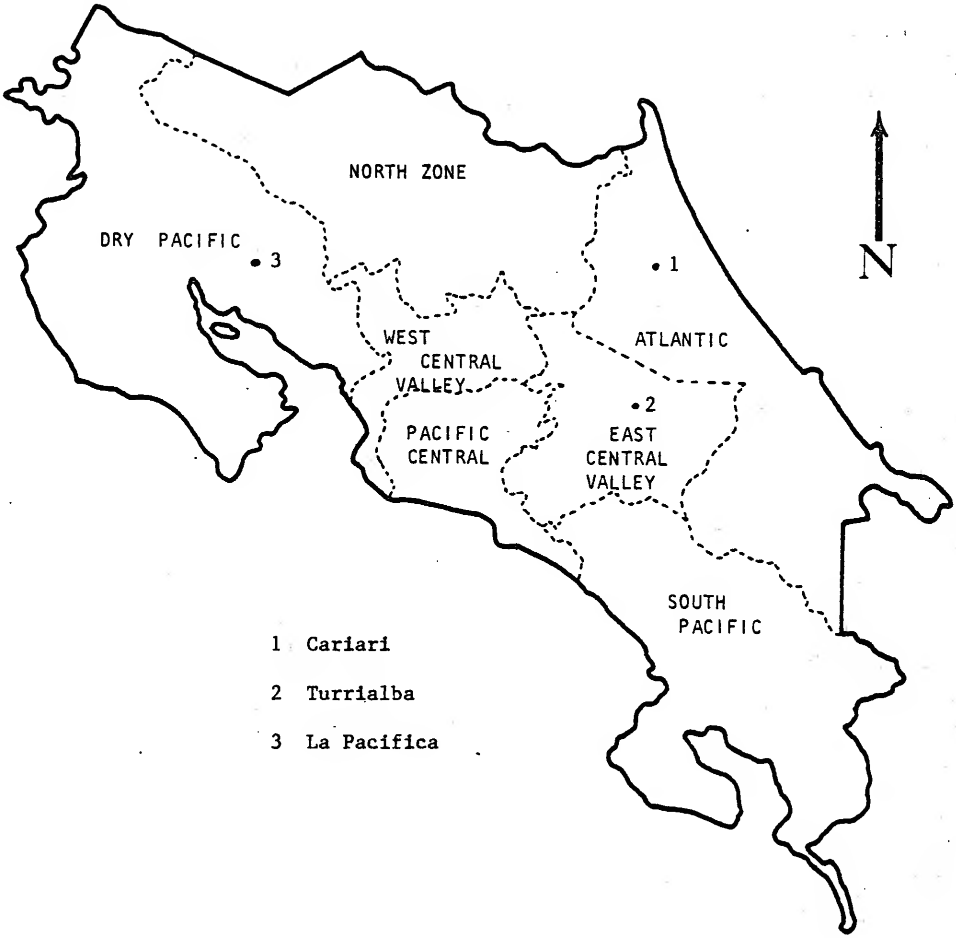


Fig. 2. Study Sites in Costa Rica

Based on: Ministerio de Economía, Industria y Comercio, Dirección General de Estadística y Censos, Censos Nacionales de 1973, Agropecuario, Regiones Agrícolas, Vol. 7, San José: Ministerio de Economía, Industria y Comercio, Dirección General de Estadística y Censos, 1975.

Table 4. Temperature and precipitation, Turrialba, Costa Rica.

Month	Maximum Temperature (°C)	Minimum Temperature (°C)	Median Temperature (°C)	Precipitation (mm)
January	25.4	16.3	20.4	173.4
February	25.8	16.2	20.6	135.9
March	26.6	16.9	21.3	77.9
April	27.1	17.6	21.8	212.9
May	27.6	18.4	22.4	221.7
June	27.4	18.6	22.3	285.3
July	26.9	18.5	22.2	283.9
August	27.2	18.3	22.1	239.3
September	27.5	18.4	22.3	245.0
October	27.3	18.3	22.0	247.7
November	26.2	18.1	21.6	281.4
December	25.6	17.1	20.8	338.4
Annual	26.7	17.7	21.6	2,651.7

Source: Instituto Meterológico Nacional. 1979c. Weather Records for Turrialba, Costa Rica. San José: Instituto Meterológico Nacional.

2651.7 mm per year, based on a period of record from 1942 to 1978. There is a dry season, from January to April, but it is not nearly as pronounced as the severe dry season experienced on Costa Rica's Pacific side, and it is possible to raise two crops per year without irrigation.

The research in Turrialba was carried out at the CATIE Department of Animal Production's field station. A milk production module that reproduces conditions common to small farms in Costa Rica, and particularly around Turrialba, has been established on the experimental farm. It is operated by a CATIE employee with the same limited resources, by and large, that are typical for small dairy producers. The unit is specialized for milk production, but some cash crops are grown, such as corn, cassava, and plantains. While conditions on the module are not an exact replica of a small dairy farm in the area, they do reproduce the small producer's situation fairly well. In addition, working at the research station offered benefits in terms of needed control over experimental conditions.

Dairying is very important in the Turrialba area. Avila's (1979) study provides a good description of the small dairy farm in the zone. Since milk and cheese production are very important elements in the farming system, most of the area of the farm is typically devoted to pasture. Nonetheless, some portion of the farm is also usually devoted to cash crop production. In Turrialba, coffee and sugar cane are the most important cash crops. Other crops may be grown, both for sale and for home consumption, and small animals, especially chickens, are very important. From the point of view of

organic fertilizer use, the role of cane and coffee on dairy farms here is very important. Coffee often receives fertilizer, currently a cash input, and sugar cane can provide a good source of raw green material for composting, a severe constraint in some locales.

Cariari

Cariari, lying 50 m above sea level, is an agricultural colony on Costa Rica's Atlantic Lowlands (see Fig. 2). No meterological station is maintained by the National Meteorological Institute in Cariari. Data are available from nearby Guapiles and, for selected years, from private banana plantations around Cariari. For descriptive purposes the data from Guapiles are sufficiently representative of the climate. For the 1961-78 period of record, rainfall averaged 4,421.6 mm annually (Instituto Meterológico Nacional, 1979a). There is no true dry season, but rainfall does decline to 200 to 300 mm per month in January, February, and March (see Table 5). The mean annual temperature is 24.6°C, and monthly means vary little from the annual mean. The diurnal fluctuation is similar to that in Turrialba, about 10°C, with a mean maximum temperature of 29.5°C and a mean minimum temperature of 19.8°C. The period of record for temperature data extends from 1942 to 1978.

Cariari was established by Costa Rica's Institute of Land and Colonization (ITCO) eighteen years ago as part of the country's agrarian reform program. The country has invested heavily in the colony. Schools, medical facilities, and roads have all been constructed, and various government agencies maintain personnel and/or offices in the colony. A highway connecting the capital to Guapiles,

Table 5. Temperature and precipitation, Guapiles, Costa Rica.

Month	Maximum Temperature (°C)	Minimum Temperature (°C)	Median Temperature (°C)	Precipitation (mm)
January	28.5	18.9	23.7	300.1
February	28.7	18.3	23.3	215.5
March	29.4	18.8	24.3	207.4
April	29.5	19.5	24.6	247.6
May	30.3	20.4	25.3	413.5
June	30.1	20.4	25.3	434.5
July	29.2	20.6	24.9	493.5
August	30.0	20.5	25.1	403.5
September	30.3	20.3	25.2	344.5
October	29.9	20.2	25.0	436.6
November	29.1	20.3	24.4	495.6
December	28.5	19.4	23.7	516.0
Annual	29.5	19.8	24.6	4,421.6

Source: Institutio Meterológico Nacional. 1979a. Weather Records for Guápiles, Costa Rica. San José: Instituto Meterológico Nacional.

the local regional center, is currently under construction. It is hoped that the agricultural potential of the area, given its high rainfall and relatively fertile soils, especially in Cariari, will provide a good return on this investment.

Each settler in Cariari received 20 ha of land. Large areas of the farms are in unimproved pasture, and cow-calf operations are a very important enterprise on most farms. Pasture occupies an average of 9 ha on the farms and cattle production accounts for roughly half the farm income. Only 28% of the farms surveyed in 1979 were involved in dairying (CATIE, 1980b). The cow-calf enterprise is a low management enterprise and one that represents an unintensive form of land use. Today, marketing is a major drawback to dairying, and it is hoped that access to the San Jose milk market provided by the new highway will encourage farmers to turn to milk production. Many farmers in the area do express interest. Because of the importance of the area to Costa Rica, the emphasis on introducing milk production, and its climatic characteristics, the research was completed in the area.

Despite the importance of cattle operations, farms in Cariari almost always have mixed farming systems. Small animals, hogs and chickens, are very common, although they are usually not penned. Most farmers also plant corn, both for cash sale and for home consumption, and a wide variety of other crops, such as beans, cassava, tiquisque, banana, pejibaye palm, black pepper, and plantains, may all be found on the same farm. Thus, opportunities for the use of

fertilizer are many, although most farmers do not fertilize most of their crops or their pasture. The research program was carried out on three farms in the colony.

Cañas

Finca La Pacífica, the farm where the research was completed on Costa Rica's Pacific side, is located just north of Cañas at 50 m elevation (see Fig. 2). Total annual rainfall at La Pacífica for the period of record 1920-79 averaged 1,639 mm (Hagenhauer, 1981). However, the region experiences a strong seasonality in rainfall. During the dry season, from November to March, rainfall averages less than 100 mm per month. Further, a strong, desiccating wind accompanies the low rainfall period. Unlike Turrialba or Cariari, it is not possible to grow two crops per year without irrigation, and planting must be timed carefully to take advantage of the onset of the rains. For the period 1961-75, the mean annual temperature was 27.4°C, with very little monthly fluctuation (Table 6).

Because of the difficulties with transportation and in finding cooperators on small farms, the research was carried out on a large, commercial farm. At the time the study was started, there were no ongoing CATIE projects in the area. It was felt, nonetheless, that it was important to test the production of compost under the climatic conditions prevalent on the dry Pacific side of Costa Rica, and it was possible that CATIE projects would be started in nearby Nicoya, with its similar climate.

Later, CATIE projects were undertaken in La Sierra (Santa Elena). This area differs from La Pacífica in that it has a higher elevation

Table 6. Temperature and precipitation, Finca La Pacífica, Cañas, Costa Rica.

Month	Maximum Temperature (°C)	Minimum Temperature (°C)	Median Temperature (°C)	Precipitation (mm)
January	31.9	23.2	27.3	3.7
February	32.5	25.2	27.7	15.0
March	33.4	23.7	28.2	8.0
April	34.3	24.2	28.6	44.0
May	33.7	23.7	28.2	141.9
June	31.8	22.8	27.0	264.8
July	31.7	23.2	27.2	114.4
August	32.1	22.8	27.3	155.6
September	31.9	21.9	26.8	294.6
October	31.4	22.0	26.6	297.5
November	30.9	22.1	26.5	98.8
December	31.0	22.6	26.8	20.1
Annual	32.2	23.1	27.4	1,639.0

Source: B. Hagenhauer. 1981. Unpublished Weather Data for Finca La Pacífica, Cañas, Costa Rica.

(900 to 1,500 m), and correspondingly cooler temperatures, but it shares the strong seasonal precipitation pattern and wind, and pulsed crop production, with the lowlands. La Sierra itself can be divided into two zones, the lower (900 to 1,100 m) and the upper (1,100 to 1,500 m). When the CATIE projects were undertaken in La Sierra, compost was made and applied there and farmers were interviewed, even though the complete research program could not be completed.

Farms in the upper zone are strongly specialized in milk production. With an average farm size of 19 ha, 15.5 ha are occupied by pasture and 95% of the family income comes from milk production. In the lower zone, farther from the cheese plant which is the market for milk, 15.5 ha of an average farm size of 29 ha are devoted to pasture and only 36% of the family income comes from dairying. Production from coffee accounts for an almost equal share of family income in the lower zone, 32% (CATIE, 1980b). Farmers in the upper zone expressed interest in using compost to fertilize vegetable plots, part of which may go for sale, and to apply to tall grass pasture (which is cut during the dry season). In the lower zone, coffee needs fertilizer, but, unfortunately, farms there are less well equipped to collect and utilize manure. They have fewer cows, generally milk only once per day, and are less apt to milk under cover.

Figure 3 shows the rainfall pattern at the three study sites. Precipitation distribution was an important parameter for this research for two reasons. First, different problems are encountered

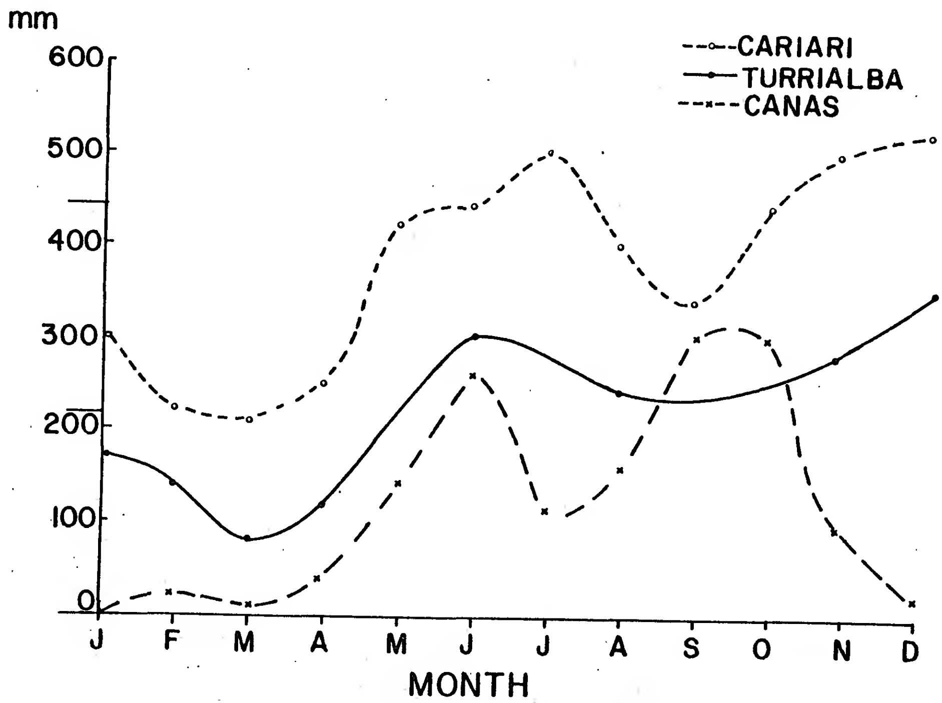


Fig. 3. Rainfall distribution at the three study sites.

in producing compost under high rainfall and low rainfall conditions. Second, periods of peak demand for fertilizer vary with rainfall distribution. When there is only a single growing season, as at La Pacifíca, for example, the farmer will need to produce large amounts of organic fertilizer for use at one time. In a site like Cariari, demand for fertilizer is much less pulsed. Temperature was a relatively unimportant factor here because none of the study sites has an elevation sufficiently high to produce night temperatures low enough to affect the composting process significantly. Temperature would, however, be an important variable in higher elevation locations.

CHAPTER III
LITERATURE REVIEW

The use of animal manure and other organic materials as a soil amendment is an ancient practice. No literature review could adequately cover the volumes of material that have been written on this subject. Further, much of the detailed information regarding composting is described below in the discussion of the results obtained by the author in Costa Rica. This brief review will familiarize the reader with the major sources of information that are available.

The Composting Process

The compost heap is an ecosystem in which optimal growing conditions for a wide range of bacteria, fungi, and actinomycetes are provided (Allen, 1949-50; Cooney and Emerson, 1964; Waksman, Umbreit, and Cordon, 1939). By providing optimum growing conditions for these organisms, the rate of decomposition is increased so that a stable organic complex can be produced rapidly (Grossman and Thygeson, 1974). Achieving stability is important because the addition of only slightly decomposed material to the soil results in increased growth and activity of soil microbiota. Since these organisms can more readily extract plant nutrients, especially nitrogen, from the soil than most higher plants, enhanced levels of microbiological activity are not desirable for crop production. The main factors which must be controlled to achieve high decomposition rates are moisture content, aeration, carbon to nitrogen (C:N) ratio, pH,

phosphorus and potassium content, temperature, and micronutrient supply (Gotaas, 1956; Taiganides, 1977; Toth, 1973).

Many techniques for composting have been developed. Krishnamurthy (1966) reviews the major techniques that have been developed in India, one of the nations where ongoing research has been conducted for many years. McGarry and Stainforth (1978) and the 1977 FAO report on the use of organic wastes provide a good discussion of composting techniques in the People's Republic of China, where compost is a very important source of fertilizer. For a general review of the basic methods of composting, Gotaas (1956) is excellent, and Golueke (1972) and Poincelot (1974) also discuss the critical parameters in composting.

High temperature, aerobic composting is generally preferable to anaerobic and/or mesophilic composting. The latter are possible, however, and are often intentionally included as stages in composting. High temperature composting is rapid and maintenance of aerobic conditions eliminates foul odors, minimizes fly problems, and leads to less nutrient loss by leaching than other methods. Barring extreme external environmental conditions, the process is self-regulatory. An initial population of mesophilic microorganisms is replaced by a thermophilic population as the temperature of the compost rises, a result of the microbial activity itself (Bagstam, 1979). There is no distinct temperature at which the microbiotic population can be said to be thermophilic as opposed to mesophilic, although many authors (Golueke, 1972; Poincelot, 1974; Taiganides, 1977) define the mesophilic range of activity as 20 to 40°C and the thermophilic

range as 40 to 70°C. This definition of thermophily is accepted for purposes of this discussion.

The number and type of organisms in compost heaps change greatly over time. Early efforts to identify the organisms responsible for decomposition in compost, especially the thermophiles involved, and to determine the nature of their activity, include Allen's (1944-50) work, that of James, Rettger, and Thom (1941), the work of Carlyle and Norman (1941), and Gaskill and Gilman's (1939) work on nitrogen transformations. Poincelot (1974) gives a list of those organisms believed to be most important in composting.

Waksman, Unbriet, and Cordon (1939) described the basic nature of the populations involved. They found that fungi are initially more prevalent, but that as temperatures rise to 50°C or more bacteria and actinomycetes (which are usually treated separately because of their importance in composting) predominate. Bagstam (1978, 1979) studied population changes in a spruce bark compost and also found that the importance of bacteria increases as temperature rises. He found that fungi were least tolerant of high temperatures, followed by the actinomycetes species, and that bacteria accounted for 90 to 100% of the microorganism population during the thermophilic stage. Polprasert, Wangsuphachart, and Muttamara (1980) found, however, that both thermophilic bacteria and cellulytic fungi were active at the 40 to 60°C temperature range and that mesophilic bacteria and actinomycetes became more prevalent as temperatures fell to 35 to 40°C. The role of the fungi is particularly important because some species are able to degrade lignin (Cooney and Emerson, 1964; Jain, Kapoor,

and Mishra, 1979), and because of their efficiency in attacking cellulose (Cooke, 1977). Actinomycetes and bacteria are more limited in the range of substances they easily attack (Waksman, Cordon, and Hulpoi, 1939).

Prior to World War II, when organic materials were the primary sources of plant nutrients, a great deal of literature dealing with the properties and utilization of manure in general, and compost in particular, was produced (Heck, 1931; Murray, 1925; Richardson and Wang, 1942; Salter and Schollenberger, 1939; Thorne, 1913; VanVuren, 1948). As chemical fertilizer became inexpensive, little research in the use of compost was completed in most regions of the world. China and India were exceptions, and in the United States the ongoing support of a group interested in organic gardening was an exception as well (Fukuoka, 1978; Rodale, 1945; Wolf, 1977). In addition, some researchers in Europe (Garner, 1966; Hemingway, 1961; Richardson, 1946) continued to investigate the use of organics, as did researchers in countries where chemical fertilizers continued to be relatively expensive and difficult to procure (Bache and Heathcote, 1969; Grimes and Clark, 1962; Jameson and Kerkham, 1960; Wood, 1963). Interest in Latin America was apparently very restricted.

In recent years interest has grown again, partly because of rising fertilizer costs and partly because of renewed interest in "organically" grown food. Perhaps even more important in the United States, disposal of sewage sludge, solid waste, and animal feedlot wastes has become an increasingly severe problem. Land application of these wastes is one alternative and has become an area of great interest.

Much of this research, however, is not of great utility from the point of view of achieving maximum utility of organic materials as a fertilizer because the central research problems are defined differently. When composting is seen as a method of disposing of large amounts of waste, rapidity of the process and reduction in bulk are stressed; nutrient retention is not necessarily a goal. The systems designed by such researchers are highly technical and are not appropriate to small farm conditions, nor are they, of course, intended for such use (Satriana, 1974; Sikora et al., 1979; Sikora et al., 1981; Willson et al., 1980). Even where disposing of animal wastes is the object of the system design, scale and technology are inappropriate for farms in developing nations (Demmel, 1980; Taiganides, 1977; Willson, 1971).

Further, when these organic materials are seen as wastes, the question of maximum loading rates and problems associated with excessively high application rates are critical research priorities (Adriano, Pratt, and Bishop, 1971; Clapp et al., 1978; Concannon and Genetelli, 1971; Hileman, 1971; Stewart and Meek, 1977). These are less apt to be critical questions where disposal of large amounts of material is not a problem.

Nonetheless, as the discussion of the results obtained in Costa Rica shows, this most recent research has improved greatly out understanding of the nature of composting. Recent findings on the effects of C:N ratios and temperature, for example, have design implications even for very low-technology systems. Similarly, the recent findings regarding effects of organic materials on soils are often very useful.

Plant and Soil Response to Organic Fertilizers

Use of fresh manures and composts has resulted in both the improvement of the physical properties of soils and an increased crop production. Manuring adds organic matter as well as plant nutrients to the soil, which is believed to increase the soil's nutrient retention capacity. If applied on the surface, it prevents crusting, whereas mixing manure into the soil by tillage improves the soil structure and physical conditions (North Carolina Agricultural Extension Service, 1973b). In addition, compost increases the moisture retention capacity of the soil and conserves soil water (North Carolina Agricultural Extension Service, 1973a; Rodale, 1945). Organic fertilizers also reduce erosion through the interaction of three interconnected factors. If manure is on the soil surface, or only slightly tilled, it protects the soil from the force of falling raindrops. It also helps hold water and thus prevent runoff, and it promotes soil aggregation, all of which help reduce erosion.

Many authors (Bache and Heathcote, 1969; Djokoto and Stevens, 1961a, 1961b; Jameson and Kerkham, 1960) have commented on the value of manure in maintaining soil fertility. As Guinard (1967) points out, unlike chemical fertilizers, the effects of applying manure are prolonged, providing an ongoing release of plant nutrients. Crop yields are increased by manure application, and several experiments have dealt specifically with improved yields in tropical areas (Agboola et al., 1975; Grimes and Clarke, 1962; Hartley, 1937; Hartley and Greenwood, 1933).

The debate over the nutritive value of "organically" versus "chemically" grown foods is an ongoing one, but of little relevance here. Long-term experiments have been undertaken to determine, for example, the effects of organically versus chemically fertilized feedstuffs on animal health (Bruin, 1969), but no conclusions have been drawn. More recently, concern over pollution effects of chemical fertilizer use has also been expressed (Molen, 1974). While these may be critical issues, the point of this study is to look at the feasibility of supplementing or replacing chemical fertilizer use by organics from an economic viewpoint. The preferability of doing so, from other points of view, is not considered.

Potential Problems in Using Organic Fertilizers

Despite the highly beneficial aspects of organic fertilizers, problems with their use may still arise, a few of which are discussed here. Problems of a soil chemical nature are dealt with only briefly because they are much more likely to arise where very large quantities of material are being applied to the soil. While these problems could come to the fore with continued application of compost over many years, they are not likely to be a serious drawback to the use of compost in developing nations. Health hazards are dealt with at more length.

Human and animal wastes are quite high in salt content, and problems of salt accumulation in soils have arisen when they are applied in large quantities. Salt toxicity to plants is a problem when conductivity (EC) exceeds 0.05 mmho in a 1:2 soil-water slurry, and is a very serious problem at values greater than 1.0 mmho (Hileman,

1971). Excessive salinity can also cause soil structure deterioration. Some salt cations, mainly sodium, cause soil particles to disperse, which will eventually greatly retard water movement through the soil (Travis et al., 1971). While such problems have largely resulted from very high rates of slurry application, the same results can come about from high, prolonged levels of manure, sludge, and compost use.

The use of poultry litter in northwestern Arkansas, practiced for over 30 years, has caused soil chemical imbalances. Hileman (1971) applied broiler litter at rates of 5, 10, 15, and 20 tons per acre and found that soil pH rose in all cases. It is believed that ammonia released during decomposition of the litter may affect the soil exchange complex, affecting calcium, potassium, and magnesium ionic replacement and resulting in high levels of these salts in the soil and high pH values. The rise in soluble salts was found to vary with soil texture. Hegg and Skipper (1977) found that yields were lower when poultry effluent was applied to soils than when synthetic fertilizers containing equivalent amounts of nitrogen were used, and conclude that salt toxicity could be one reason for the decline. Although the salt content of poultry manure is considerably higher than that of cattle manure, salt accumulation has also been high when beef feedlot manure and lagoon water were applied to soils (Wallingford et al., 1975, 1976).

Heavy metal contamination may also be a problem, although it is one that is much more apt to arise where sewage sludge from urban sources is applied to the land. Of most concern are lead, zinc,

copper, nickel, and cadmium (United States Department of Agriculture, 1978). This problem is complicated by the fact that differences in soil chemical and physical properties affect retention in the soil of these metals, and subsequent uptake by plants. Chubin (1981) found, for example, that cadmium uptake was influenced by soil pH and CEC, and that, in some cases, zinc and cadmium uptake were related as well. Further, as Willson et al. (1980) note, plant species, and even varieties within species, differ in uptake and translocation of heavy metals. While heavy metal contamination is not likely to be a problem using compost made of animal manure, this possible source of hazard should be kept in mind.

Finally, problems can also result from the high biological oxygen demand (BOD) or organic wastes, which can result in anaerobic soil conditions. Such problems have been reported in Europe and North America, but will probably be much less serious in developing nations where manure or compost is more likely to be used than lagoon water. One advantage of compost is that its BOD is low because decomposition has already occurred. Nonetheless, soils can become anaerobic from the high BOD of manure, especially very wet soils. Such conditions cause denitrification, and many of the products of anaerobic decomposition, such as organic acids, are harmful to plants (McCalla et al., 1970).

Because of the possibility of transmitting disease causing organisms, the use of organic wastes, especially manure, as a fertilizer has caused concern. In addition, dung heaps and compost piles can become attractants for flies, both a nuisance factor and a health

hazard to the degree that the enhanced fly population itself promotes the spread of disease (Anderson, 1967). Over 100 diseases that can be passed from animals to man are known and could be a problem where manure is used as a fertilizer (Decker and Steele, 1967). It night-soil is used, especially in areas with high levels of infection in the population, health problems are particularly important.

The health hazard associated with the use of organic fertilizers will depend on the incidence of viable pathogens in the fecal waste material, the survival rate of these organisms in the compost, and the epidemiology or mode of transmission of the organism. Table 7 lists some of the organisms and diseases that are of special importance to the discussion here because of their prevalence in tropical regions and their ease of transmission to man (see Faust, Beaver, and Jung, 1975; Metcalf, 1976; National Academy of Sciences, 1977; Swellengrebel and Sterman, 1961). Pathogens which cannot pass more or less directly from human or animal feces to the soil or crop, and then to the human vector, are relatively unimportant. For example, <u>Schistomata japonicum</u> (the blood fluke) is a relatively common pathogen, causing schistosomiasis, in the tropics. It is not very important, however, to this discussion because an intermediate host, a snail, is required to complete its lifecycle (Faust, Beaver, and Jung, 1975).

Composting has proven effective in destroying these pathogens. Gotaas (1956) reports that virtually all of the bacterial, protozoan, and helminthic organisms in Table 7 have been shown to be destroyed in properly prepared compost. Maintenance of high temperatures and

Table 7. Pathogens of special concern when using manure as a fertilizer.

Type	Organism	Disease
Bacterial	Salmonella typhosa	Typhoid fever
	Salmonella spp.	Salmonellosis
	Shigella spp.	Bacillary dysentery
	Vibrio cholerae	Cholera
	Mycobacterium tuberculosis	Tuberculosis
Protozoan	Endamoeba histolytica	Amebic dysentery
Helminthic	Ascaris lumbricoides	Roundworm
	Oxyaris vermicularis	Pinworm
	Thichuris trichuria	Whipworm
	Taenia saginata	Tapeworm
	Taenia solium	
	Strongyloides stercoralis	
	Hymenolapis nana	
	Andyostoma duodenale	Hookworm
	Necator americanus	
Viral	Adenoviruses	Eye, respiratory infections
	Coxsackievirus A	Aseptic meningitis, congenital heart anomalies, diabetes (?), fever, herpangina, myocarditis and pleurodynia
	Echovirus	Aseptic meningitis, diarrhea, rash and respiratory infections
	Poliovirus	Aseptic meningitis, poliomyelitis
	Infectious hepatitis virus	Infectious hepatitis
	Parvoviruses	Acure infections non-bacterial gastroenteritis
	Reovirus	Diarrhea, respiratory infections

adequate mixing of the compost are important in ensuring complete destruction. Ascaris lumbricoides is particularly important because it is extremely prevalent in man and in animals in developing areas, and because it is difficult to destroy. Gotaas (1956), for example, indicates the Ascaris eggs survived longer (22 days or more) than those of most pathogens during composting. He states that anaerobic composting may not completely destroy Ascaris eggs even in six months. McGarry and Stainforth (1978), however, found that Ascarid egg mortality was 100% in 30 days in properly managed self-composting toilets. Less is known regarding virus mortality during composting, but research findings in some cases do indicate that survival is decreased by high temperatures and prolonged storage (Sigel et al., 1976).

Control of the fly population around compost piles can be a serious problem. Scott (1952) studied this problem in China and makes several suggestions regarding fly control. Ensuring uniform exposure of the entire heap to prolonged high temperatures is crucial (Gotaas, 1956). Turning is important because the fly larvae migrate to the cooler, outer layers of the heap. Shredding may help as well. Fly control is particularly important where large amounts of fecal waste are used in the compost.

Some general comments are in order here as well. First, as Menzies (1976) points out, reclaiming wastes really involves striking an acceptable balance between the benefits derived from using the wastes and the resultant potential health risks to man and animals. In developed nations, particularly in North America, the general view

is that the health risk must be very low to make the use of organic fertilizers worthwhile. Spread of disease among animals is often cited as a major drawback to use of organic wastes, for example (Bell, Wilson, and Dew, 1976; Hojovec, 1977; Taylor, 1973; Taylor and Burrows, 1971).

In developing nations this question must be viewed somewhat differently. Failure to use organic fertilizers may mean failure to use fertlilizers at all. Even assuming that the health risk is, by North American standards, high, this risk must be balanced against the general improvement in public health that results from higher sustained yields and resultant improvements in dietary standards.

Second, where infection is endemic in the population, and especially where wastes are not treated, individuals are exposed to prevalent pathogens at an early age. Nnochiri (1975) points out, for example, that 90% of preschool children are exposed to and develop antibodies against at least one of the three types of polio in many tropical areas. While use of raw wastes as a fertilizer may be partly responsible for this exposure (Beaver and Deschamps, 1949), the problem lies with the method of application of the manure, not the use of manure as a fertilizer. Infection from manure use was once considered a serious problem in China (Faust, 1924; Lane, 1934). By stressing hygienically acceptable practices, this problem has largely been overcome (Department of Environmental Health, 1977).

Finally, composting represents an improvement of sanitary standards in many cases. Because of the high concern over health hazards in developed countries, and because of the low cost of chemical

fertilizers, wastes have been systematically destroyed, for the most part, and agriculture has been supported by an energy subsidy in the form of fossil fuels. Yet, even in those wealthy nations, it has become obvious that the substitution of nonrenewable energy and chemical resources for lost nutrients cannot go on forever. Further, the cost of destroying wastes, itself a pollution hazard and energy consumptive process, is rising. Sewage treatment is limited or nonexistent in many parts of the world, and the energy-intensive and technologically sophisticated systems in use in the United States and Europe will probably remain unavailable to much of the world's population. Composting can provide a practicable method of sanitary waste disposal (Rybczynski, 1977), and help reduce dependence on expensive fertilizer materials.

CHAPTER IV
MATERIALS AND METHODS

The study was essentially a three-stage process, and Fig. 4 provides a schematic overview of the entire experimental design. The first stage involved the actual manufacture of compost. The second stage involved utilization of the compost in field trials, using a variety of treatments on the plots, and the third stage was a survey, designed to gauge the numver of farms in each zone where the technology that was developed could be utilized. In order to facilitate the discussion here, each of these stages is described separately.

Compost Production

Two types of compost were made at each study site, unenriched and enriched. The unenriched compost consisted of a simple mixture of cow manure and corn or sorghum stover. The enriched contained a few kilograms of a complete mix fertilizer as well, 15-15-15.

The fertilizer was added to increase the phosphate content of the compost, although, of course, use of complete mix fertilizer means that nitrogen and potassium content should be increased as well. Cattle manure is very low in phosphorus, and as Lauer (1975) point out, the most serious constraint in replacing chemical fertilizer use by use of organic fertilizer made from manure is that of meeting the phosphorus requirements for plant growth. Others (Mathur, Sarkar, and Mishra, 1980; Rastogi, Mishra, and Ghildyal, 1976;

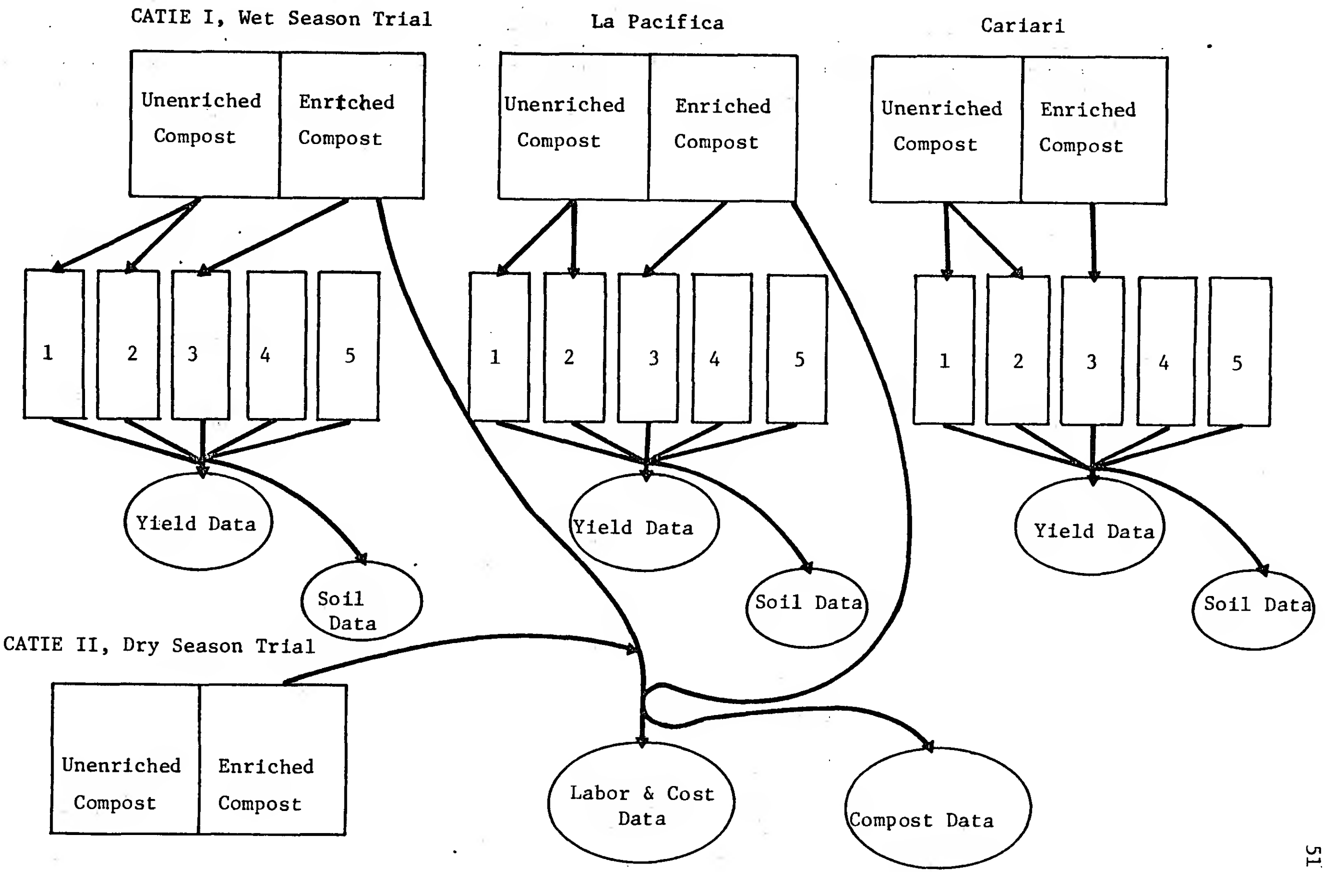


Fig. 4. Overview of Project

Sadaphal and Singh, 1979; Walunjkar and Acharya, 1955) have also attempted to overcome this problem by the addition of phosphate in some chemical form to compost. Since it is difficult and expensive to acquire superphosphate singly in Costa Rica, the phosphate was applied in a readily available and commonly used complete mix.

The manure and corn stover were placed in layers, always starting and ending with a layer of stover. It is best that the uppermost layer be one of vegetative materials, not manure, in order to avoid attracting flies and other pests. At CATIE, where large concrete pits were available, one group of replicates was constructed in those pits. In the second trial at CATIE and at the trials in Canas and Cariari, the compost was made as overground heaps. A shallow pit (30 to 50 cm deep) was dug and lined with clear plastic both to provide support and to serve as a trap for the nutrient-rich liquid that is produced during composting. In all cases, the original heap was at least 2 m long by 1.5 m wide by 1 m deep. These are the minimal dimensions that can be used because smaller heaps do not provide the mass and insulation that is needed to support the thermophilic population during the composting process. Wider heaps are apt to suffer from inadequate aeration and deeper heaps from compaction, but almost any length heap can be constructed (Gotaas, 1956). Aeration was provided by bamboo poles. The centers were removed from the bamboo shoots and holes were cut in each side to make a chimney. These were placed in the center of the heap at intervals of about 50 cm. The heaps were covered with plastic as well to provide some protection from rain and excessive desiccation. The compost was

turned at 4 and 8 weeks after construction of the heaps. Tables 8 through 11 show the materials used in the compost heaps.

The carbon, nitrogen, phosphorus, potassium and microelement content of the manure and stover, and of the finished compost were determined. In addition, all compost was sampled at 2, 4, 8, and 12 weeks after construction of the heaps and pH, humidity, and nitrogen and carbon content were determined. In the case of the first trial at CATIE, the compose was sampled at 1, 5, 6, 9, and 10 weeks after construction as well. Only pH, humidity, and nitrogen content were determined for these samples. These samples were extracted with a soil probe.

There is no commonly accepted method for determining carbon content in compost. Suzuki, Harada, and Kumada (1975) used a wet digestion procedure, whereas Abd-El-Malek et al. (1976) estimated carbon by loss on ignition in a muffle oven at 700°C for one hour, for example. Several factors may interfere with determination of oxidizable carbon using wet combustion procedures. Most important, these procedures are subject to incomplete carbon oxidation, necessitating the use of a correction factor. This factor must be determined by using some other accurate measure of oxidizable carbon. Since the relative digestibility of the remaining organic complexes in compost changes over time, the factor determined at any given time may not be correct for other samples, and a new factor should be determined for each set of samples. Similarly, a factor must be determined for each type of fresh organic material that is analyzed.

Table 8. Materials included in compost heaps, CATIE, Trial I.

	Unenriched			Enriched		
Replicate	Material[a]	Wet Weight (kg)	Dry Weight (kg)	Material[a]	Wet Weight (kg)	Dry Weight (kg)
1	Manure 2	797	136	Manure 3 and 4	1,080	189
	Corn Stover 1	596	312	Corn Stover 4	214	165
				Fertilizer	20	20
	Total	1,393	448	Total	1,314	374
2	Manure 2	730	124	Manure 3 and 4	1,080	189
	Corn Stover 2	603	456	Corn Stover 4	212	164
				Fertilizer	20	20
	Total	1,333	580	Total	1,312	373
3	Manure 2	730	124			
	Corn Stover 2	618	467			
	Total	1,348	591			

[a]See Table 44, Appendix A, for details of the chemical characteristics of the materials used.

Table 9. Materials included in compost heaps, CATIE, Trial II.

Replicate	Unenriched			Enriched		
	Material[a]	Wet Weight (kg)	Dry Weight (kg)	Material[a]	Wet Weight (kg)	Dry Weight (kg)
1	Manure	251	30	Manure	150	18
	Corn Stover	72	56	Corn Stover	99	77
				Fertilizer	3	3
	Total	323	86	Total	252	98
2	Manure	252	30	Manure	152	18
	Corn Stover	72	56	Corn Stover	102	79
				Fertilizer	3	3
	Total	324	86	Total	257	100
3	Manure	253	30	Manure	150	18
	Corn Stover	72	56	Corn Stover	100	77
				Fertilizer	3	3
	Total	325	86	Total	253	98

[a]See Table 45, Appendix A, for details of the chemical characteristics of the materials used.

Table 10. Materials included in compost heaps, Cariari.

Replicate	Unenriched			Enriched		
	Material[a]	Wet Weight (kg)	Dry Weight (kg)	Material[a]	Wet Weight (kg)	Dry Weight (kg)
1	Manure 2 and 3	162	39	Manure 2	70	23
	Corn Stover	39	34	Corn Stover	42	32
				Fertilizer	3	3
	Total	301	102	Total	115	58
2	Manure 1, 2 & 3	470	112	Manure 2 and 3	77	18
	Corn Stover	41	31	Corn Stover	60	45
				Fertilizer	4	4
	Total	511	143	Total	141	67
3	Manure 2 and 3	179	35	Manure 2	70	23
	Corn Stover	39	29	Corn Stover	60	45
				Fertilizer	4	4
	Total	218	64	Total	134	71

[a]See Table 46, Appendix A, for details of the chemical characteristics of the materials used.

Table 11. Materials included in compost heaps, La Pacífica.

Replicate	Unenriched Material[a]	Unenriched Wet Weight (kg)	Unenriched Dry Weight (kg)	Enriched Material[a]	Enriched Wet Weight (kg)	Enriched Dry Weight (kg)
1	Manure	435	159	Manure	275	100
	Sorghum Stover	94	55	Sorghum Stover	96	56
				Fertilizer	4	4
	Total	529	214	Total	375	160
2	Manure	475	173	Manure	275	100
	Sorghum Stover	106	62	Sorghum Stover	96	56
				Fertilizer	4	4
	Total	581	235	Total	375	160
3	Manure	475	173	Manure	275	100
	Sorghum Stover	104	61	Sorghum Stover	96	56
				Fertilizer	4	4
	Total	579	234	Total	375	160

[a] See Table 47, Appendix A, for details of the chemical characteristics of the materials used.

Gotaas (1956) suggests that ashing in a muffle oven is adequate. He reports that results within 2 to 10% of more accurate determinations were found using this method. Schulze (1960) gives the formula:

$$\%C = \frac{(100 - \%\ Ash)}{1.8}$$

for determining carbon by ashing.

No muffle oven was available and, given the inherent problems with wet digestion procedures, the best alternative was to use a carbon-hydrogen analyzer. This is a very accurate, but time-consuming and expensive method for determining carbon. Dried, finely ground (80 mesh sieve) samples were used. A 0.01 g sample was combusted at approximately 850°C for six minutes.

Total nitrogen was determined using the micro-Kjeldahl method (Bremmer, 1965; Hesse, 1971). Samples were digested for one hour. Comparison of findings when the same samples were also digested for 2, 3, and 4 hours showed no differences from the results obtained with one hour of digestion. Samples were oven dried at 80°C and ground (40 mesh sieve) prior to analysis.

The solution for determination of phosphorus, potassium, and microelement content was extracted with a heated mixture of perchloric and nitric acid, and total phosphorus was determined volumetrically. Calcium, magnesium, copper, iron, manganese, zinc, and aluminum were determined by atomic absorption spectrometry (Willard, Merritt, and Dean, 1974).

Determining the pH of the compost sample presented some difficulties. Although pH is a frequently measured characteristic of compost, most authors fail to indicate how they determine pH (Galler and Davey, 1971; Golueke, Card, and McGaukley,1954; James, Rettger, and Thom, 1941; Poincelot, 1974; Willson and Hummel, 1975). Schulze (1962) measured pH by placing a 20 g sample of compost in a beaker and adding enough distilled water to completely cover the sample. The sample was stirred prior to determining pH.

The literature discussing pH testing in soils indicates the range of problems that are encountered in making this determination. These same problems can be expected to occur in the case of organic materials such as compost. Use of $CaCl_2$ or KCl in the solution gives a lower pH reading because of the replacement of H and Al cations on the exchange sites by Ca or K cations (Pearson and Adams, 1965). The magnitude of this effect in compost samples is not discussed in the literature. Using distilled water avoids these problems, but even where distilled water is used, increasing the dilution factor in the sample decreases the salt concentration and increases the pH value (Heese, 1971; Peech, 1965). No standard dilution factors for compost samples have been established. Finally, in diluted samples, measuring pH in the sediment gives a different, and usually lower, value than measuring pH in the supernatant liquid (Pearson and Adams, 1965). Since high cation-exchange capacity (CEC) favors a large suspension effect, this difference could be expected to be rather large in compost samples. Further, practical difficulties were encountered. Dried samples, which can be ground, do not rewet well, and may

therefore give inaccurate results. Wet samples were mixed in a blender with distilled water, but this required a high degree of dilution.

Because of these problems another method was used. A wet sample was placed in a metal sleeve with small holes in the sides. The sleeve was placed on a platform and elevated so that a metal core, nearly the same diameter as the sleeve, was gradually inserted, compressing the sample. The sample was compressed until it refused to yield further liquid, and the liquid exuded under pressure was collected. The pH of the liquid, which was murky but clear of sediment, was measured with glass electrodes. This method has been successfully used at CATIE to measure pH of ensilage, a material similar to compost in its physical properties.

The temperature of the compost, especially the first trial heaps at CATIE, was monitored. A special thermometer, over one meter long, was made for this purpose by inserting a glass submersion thermometer in a metal tube so that the tip of the glass thermometer fit into a tip formed on the tube. A window in the tubing permitted the user to read the temperature. Comparing the temperature reading on this thermometer with that on an unenclosed glass submersion thermometer showed that there was no appreciable difference if the metal apparatus was left for at least four minutes in the medium. The inside of the metal tube was also stuffed with aluminum foil to increase conductivity.

The temperature of the heaps at CATIE was measured regularly and frequently, daily for one week after turning and every third day otherwise, but this was not possible at Cañas and Cariari. Even though thermometers were left at those sites with the cooperators, there was a tendency for the individuals concerned not to record the temperature. Periodic readings showed that the temperature was adequately high, but the scanty data make it impossible to compare temperature curves at the three sites.

Obtaining representative samples from a compost heap is difficult because it is not a uniform medium. This is especially true prior to the first turning of the heap, when the manure and vegetative material are still layered, and when the material is still largely decomposed. Even after turning, the heap may still not be very uniform. Suzuki and Kumada (1976) found, for example, that six distinct layers formed over a one-year period of time in a heap formed of manure and sawdust. Such distinct strata are not visible in heaps that are turned more frequently. In order to overcome this problem, each sample consisted of three subsamples, extracted from various depths, and each heap was sampled at several spots on each sampling date. The samples were either analyzed individually to obtain an average value, or were dried, ground, and mixed together to form one sample in the case of the use of the carbon-hydrogen analyzer.

Field Trials

Corn (*Zea mays*) was planted at all study sites. Five fertilization treatments were used: (1) unenriched organic fertilizer;

(2) enriched organic fertilizer; (3) a mixture of chemical and unenriched organic fertilizer; (4) chemical fertilizer; and (5) zero fertilization. The equivalent of 100 kg nitrogen per ha was applied on all fertilized plots. Due to the deficiency of phosphate in the organic fertilizers, a chemical source of phosphorus was needed for those plots receiving compost. It was applied in the form of triple superphosphate, at such a level as to bring the total phosphate applied on all plots, except the controls, up to the total phosphate level received by the plot with the highest phosphate fertilization rate, the plot receiving both chemical and organic fertilizer. In order that all plots receive the same amount of potassium, a small amount of potassium was also applied to the plots receiving chemical fertilizer alone. The organic fertilizer was extremely rich in potassium and therefore additional potash (as KCl) was usually needed on the plots receiving chemical and mixed chemical and organic fertilizer. Tables 12 through 14 show the materials applied to the plots.

The test plots were 20 m^2 and the corn was planted at a row spacing of 75 cm, with 50 cm between hills. Four to five seeds per hill were planted, using a corn variety appropriate to local conditions (Tuxpeno in Cañas, Tico VI in Turrialba, and a local white corn in Cariari). The seed was treated with fungicide prior to planting. A randomized complete block design was employed.

The chemically fertilized plots received two applications of fertilizer. Forty percent of the total nitrogen requirement was applied at planting, as 10-30-10, along the rows. About 45 days

Table 12. Materials applied to field plots, CATIE.

Treatment	Source	Dry Weight Amount (kg/ha)	Wet Weight Amount (kg/ha)	N (kg/ha)	P_2O_5 (kg/ha)	K_2O (kg/ha)
Chemical	10-30-10	400		40	120	40
	NH_4NO_3	179		60		
	Triple Superphosphate	146			67	
	KCl	1,587				1,000
Unenriched Organic	Unenriched Compost	10,870	29,698	100	110	1,040
	Triple Superphosphate	167			77	
Enriched Organic	Enriched Compost	7,407	11,538	100	82	524
	Triple Superphosphate	228			105	
	KCl	819				516
Mixed	10-30-10	400		40	120	40
	Unenriched Compost	6,521	17,819	60	67	624
	KCl	597				376

Table 13. Materials applied to field plots, La Pacfica.

Treatment	Source	Dry Weight Amount (kg/ha)	Wet Weight Amount (kg/ha)	N (kg/ha)	P_2O_5 (kg/ha)	K_2O (kg/ha)
Chemical	10-30-10	400		40	120	40
	NH_4NO_3	179		60		
	Triple Superphosphate	49			23	
	KCl	150				94
Unenriched Organic	Unenriched Compost	6,757	13,514	100	38	128
	Triple Superphosphate	228			105	
	KCl	10				6
Enriched Organic	Enriched Compost	6,250	12,026	100	98	134
	Triple Superphosphate	210			97	
Mixed	10-30-10	400		40	120	40
	Unenriched Compost	4,054	8,108	60	23	77
	KCl	28				17

Table 14. Materials applied to field plots, Cariari, Farms I, II, and III.

Treatment	Source	Dry Weight Amount (kg/ha)	Wet Weight Amount (kg/ha)	N (kg/ha)	P_2O_5 (kg/ha)	K_2O (kg/ha)
		Farm I				
Chemical	10-30-10	400		40	120	40
	NH_4NO_3	179		60		
	Triple Superphosphate	102			47	
	KCl	86				54
Unenriched Organic	Unenriched Compost	11,494	25,207	100	78	91
	Triple Superphosphate	193			89	
	KCl	5				3
Enriched Organic	Enriched Compost	6,993	16,301	100	76	66
	Triple Superphosphate	198			91	
	KCl	44				28
Mixed	10-30-10	400		40	120	40
	Unenriched Compost	6,897	15,124	60	47	54
		Farm II				
Chemical	10-30-10	400		40	120	40
	NH_4NO_3	179		60		
	Triple Superphosphate	87			40	
	KCl	95				60

Table 14.--Continued.

Treatment	Source	Dry Weight Amount (kg/ha)	Wet Weight Amount (kg/ha)	N (kg/ha)	P_2O_5 (kg/ha)	K_2O (kg/ha)
Unenriched Organic	Unenriched Compost	10,870	26,838	100	67	100
	Triple Superphosphate	202			93	
Enriched Organic	Enriched Compost	8,264	16,935	100	91	85
	Triple Superphosphate	150			69	
	KCl	24				15
Mixed	10-30-10	400		40	120	40
	Unenriched Compost	6,522	16,106	60	40	60
		Farm III				
Chemical	10-30-10	400		40	120	40
	NH_4NO_3	179		60		
	Triple Superphosphate	111			51	
	KCl	124				78
Unenriched Organic	Unenriched Compost	10,417	20,959	100	85	96
	Triple Superphosphate	187			86	
	KCl	35				22
Enriched Organic	Enriched Compost	10,204	23,034	100	89	118
	Triple Superphosphate	178			82	
Mixed	10-30-10	400		40	120	40
	Unenriched Compost	6,250	13,726	60	51	58
	KCl	32				20

later a post-emergence application of ammonium nitrate, accounting for 60% of the nitrogen requirement was made. The compost was applied in narrow trenches, which were covered over with soil. The seed was planted directly into the compost, using a planting stick in the same manner as on all other plots. Neither the organically fertilized plots, not those receiving a mixture of organic and chemical fertilizers, received two fertilizer applications. The entire fertilizer requirement was applied at planting.

Yield of both grain and biomass was measured. After taking field weights, a sample of the grain and stover from each plot was dried at 80°C to obtain the dry weight yield.

Soil samples from each test plot were collected. The soil was sampled on four occasions: prior to planting, at planting, at about 45 days, and at harvest. Each sample consisted of three subsamples, taken at 0-25 cm. Samples were taken from within the rows, but the two outside rows in each plot were excluded from the sampling area. These samples were analyzed for pH, organic matter content, and macroelement and microelement content. The pH was determined using a 2:1 dilution with distilled water, The Walkley-Black wet digestion method was used to analyze organic matter content, and nitrogen content was determined by the semi-micro-Kjeldahl procedure (Bremmer, 1965). Double acid extraction in 0.05$\underline{N}$ HCl and 0.025$\underline{N}$ H_2SO_4 was used to prepare the solution for determining available phosphorus, potassium, and microelement content (Olsen and Dean, 1965). Available phosphorus was determined colorimetrically with a molybdate-venadate solution, and potassium and microelement content by atomic absorption spectrometry.

Labor and Survey Information

Labor was recorded for all tasks involved in the production and application of compost. The labor values are reported in man-hours per task. Although the exact kcal expenditure for each type of activity was not measured, the general value of 191.2 kcal per hour provided by Leach (1976) for agricultural work can be used in energy analyses.

Farmers in Cariari, Turrialba, and La Sierra were interviewed to determine availability of manure and vegetative materials for composting on those farms to find out current fertilizer usage, and to determine the potential for and interest in the use of compost in the three zones. A copy of the questionnaire is included in Appendix C. The farms visited were selected because further data about these farms are available at CATIE (Avila, 1979; CATIE, 1980b). A copy of the CATIE questionnaire is also included in Appendix C. Manure samples, analyzed for nitrogen content, were taken at various farms in each zone to determine whether there is wide variability in the nitrogen content of manure from one zone to another.

CHAPTER V
RESULTS AND DISCUSSION

In order to facilitate reading, the results and discussion of them will be presented in four parts. First, the results of the composting process itself are discussed; then yield data are presented. Finally, changes in selected soil chemical characteristics are described, and labor investment is detailed.

The Composting Process

Fairly complex technologies have been developed to maintain optimum conditions for thermophilic composting (Finstein, 1980; Singley et al., 1975; Schulze, 1962; Willson, 1971). Controlling the necessary factors under field conditions and at the same time using an appropriately inexpensive and simple technology is difficult and, as the discussion below shows, achieving optimal conditions is not always possible. Nonetheless, despite the imperfect environmental control that could be achieved, the data indicate that the composting process proceeded adequately in most cases. Measure of humidity, pH, C:N ratio, nitrogen content, temperature, and macro and micro-element retention are discussed here.

Figure 5 shows the C:N ratio over time in the 24 heaps that were built. As the graph shows, stability was achieved very rapidly, that is, the C:N ratio changed very little after 8 weeks, and may in fact have been stable even sooner, after about 6 weeks.

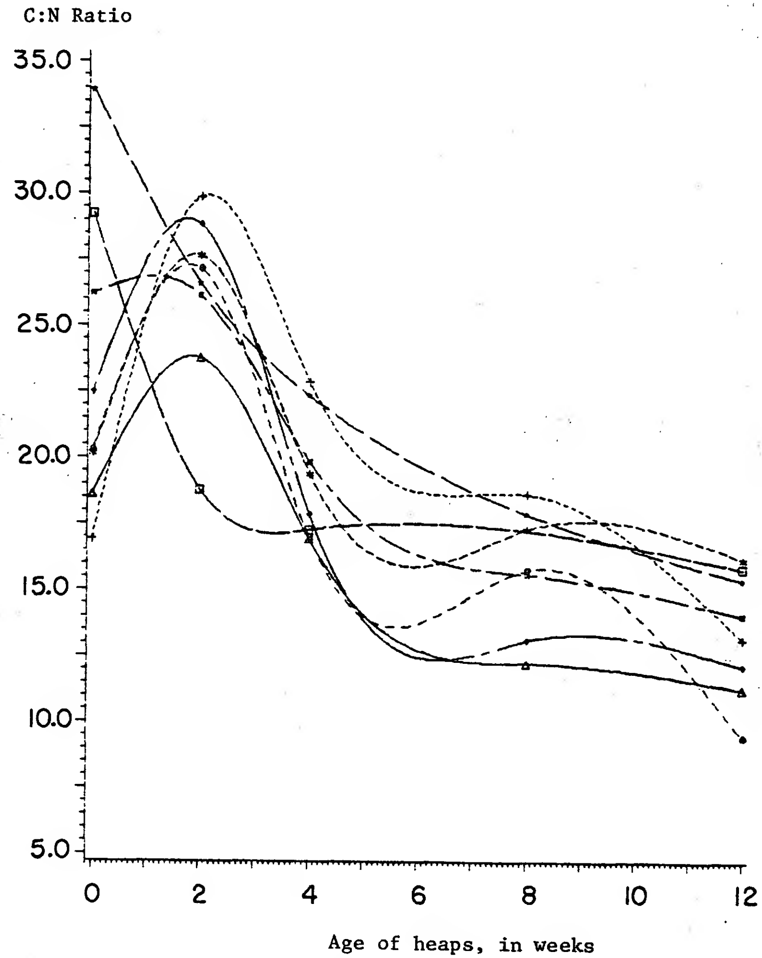
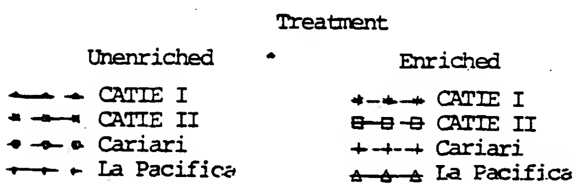


Fig. 5. C:N ratio of compost heaps.



Several methods for determining when compost is stable have been suggested. These include measures of phytotoxin production, laboratory tests utilizing rapidly growing plants or fungi as indicators, sulfide tests, nitrate tests, determination of redox potential, and detection of starch (Lossin, 1970; Spohn, 1969; Zucconi et al., 1981). Stabilization of the C:N ratio at low values (less than 20:1) is considered an adequate test of compost maturity, although perhaps not as ideal as determination of redox potential. An unchanging or very slowly changing C:N ratio indicates that further decomposition will occur only very slowly (Gotaas, 1956; Taiganides, 1977). The C:N ratios of the test heaps stabilized at values of 10:1 to 17.5:1, well within the accepted range.

The rapid stabilization of the compost is somewhat surprising given the technology used. Using highly sophisticated systems where temperature and oxygen supply are completely controlled, and where the compost is continually turned in a bench-scale drum, composting time has been reduced to as little as 7 to 10 days (Galler and Davey, 1971; Schulze, 1962; Willson, 1971). The test heaps, however, were turned only twice and the only source of aeration was bamboo chimneys. Thus, the more normal four to six months usually required to reach stability under such conditions would be expected.

Polprasert, Wangsuphachart, and Marramara (1980), in their discussion of composting nightsoil and water hyacinth in the tropics, also noted a very high rate of decomposition during the first 16 days of the process, followed by a more prolonged period of lower activity, and apparent stability of the product at 60 to 72 days, using a

similar composting procedure to that utilized here. Strom, Morris, and Finstein (1980), on the other hand, found that up to 10 months were needed to stabilize leaf compost, using a similar technology in a mid-latitude setting. Similarly, Duthie (1937) found that maize straw composted under tropical conditions for 107 days reached the same degree of decomposition as rye straw composted 290 days in a mid-latitude setting, as measured by content of hydrolyzable cellulose and hemicellulose and lignin. These divergent results suggest that the process may be much more rapid in the tropical setting. However, no definitive conclusions can be drawn because of the wide variety of materials and methods used, and the scarcity of information on composting under tropical conditions.

The extreme rapidity of the process reported here suggests that there is indeed a pronounced difference in the process between mid-latitude and tropical situations. If so, this probably is due to the relatively high mean daily temperature and the low daily or periodic fluctuation in temperature typical of the tropical setting, rather than differences in microbial populations. Even where innoculums (Golueke, Card, and McGauhley, 1954; Greenstreet, 1928; Obrist, 1966) or cultures of pure and mixed microorganisms (Waksman and Cordon, 1939) have been purposely introduced into compost, no significant differences in composting rate have been reported. Under cold conditions, however, the process is greatly slowed, and even under cool conditions some portion of the outer layer of the heap will be relatively inactive (Lambert, 1934).

Temperature was carefully monitored in the first group of heaps constructed at CATIE, and Fig. 6 shows the temperature curves of these heaps during the process. Although the data are incomplete, temperatures at La Pacífica are also shown to provide a point of comparison (Fig. 6). These curves also suggest that microbial activity was greatly reduced after 60 days. As the graph shows, the temperature increased after turning at 30 days, and the average temperature (although not the maximum temperature in the unenriched heaps) then dropped below the generally accepted thermophilic boundary of 37.5°C at roughly 45 days. The second turning, at 60 days, produced a slight temperature increase, but generally failed to raise biological activity to the thermophilic level again. Although temperature could not be monitored as thoroughly at other sites, the temperature readings that were taken suggest a similar pattern at all three locations, and later in the Santa Elena site as well, although maximum temperatures recorded at Cariari and Santa Elena were never as high as those recorded at CATIE and La Pacífica.

Obtaining representative temperature readings from a compost heap is difficult because the temperature is not uniform throughout. Suzuki and Kumada (1976) found that temperature differences in the various zones of a compost heap persisted even when it was left unturned for a period of one year, and Strom, Morris and Finstein (1980) found similar zonal differences in recently constructed heaps. The values reported in Fig. 6 are averages of readings extracted at eight predetermined locations and at two to four depths at each location (depending on the degree to which the height of the heap had decreased)

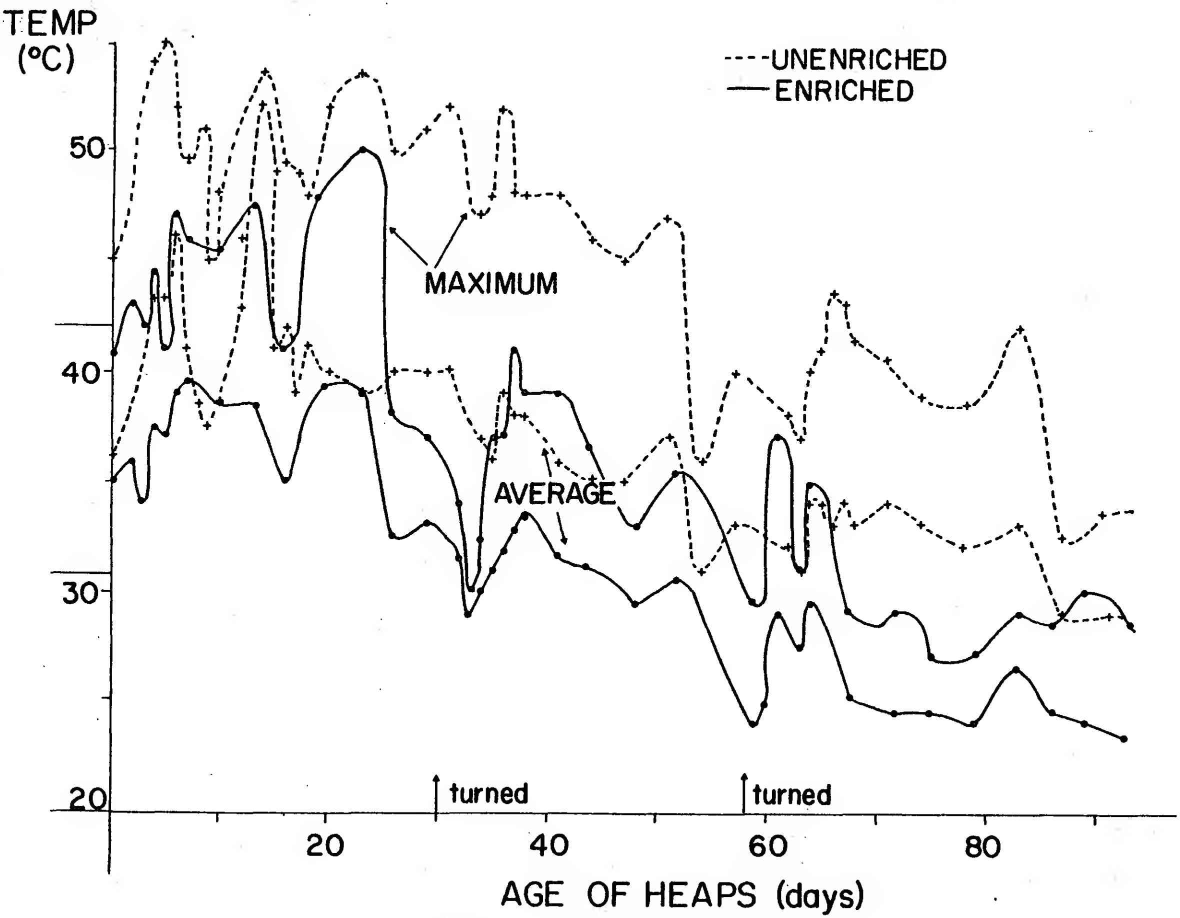


Fig. 6. Temperature in compost heaps, CATIE I

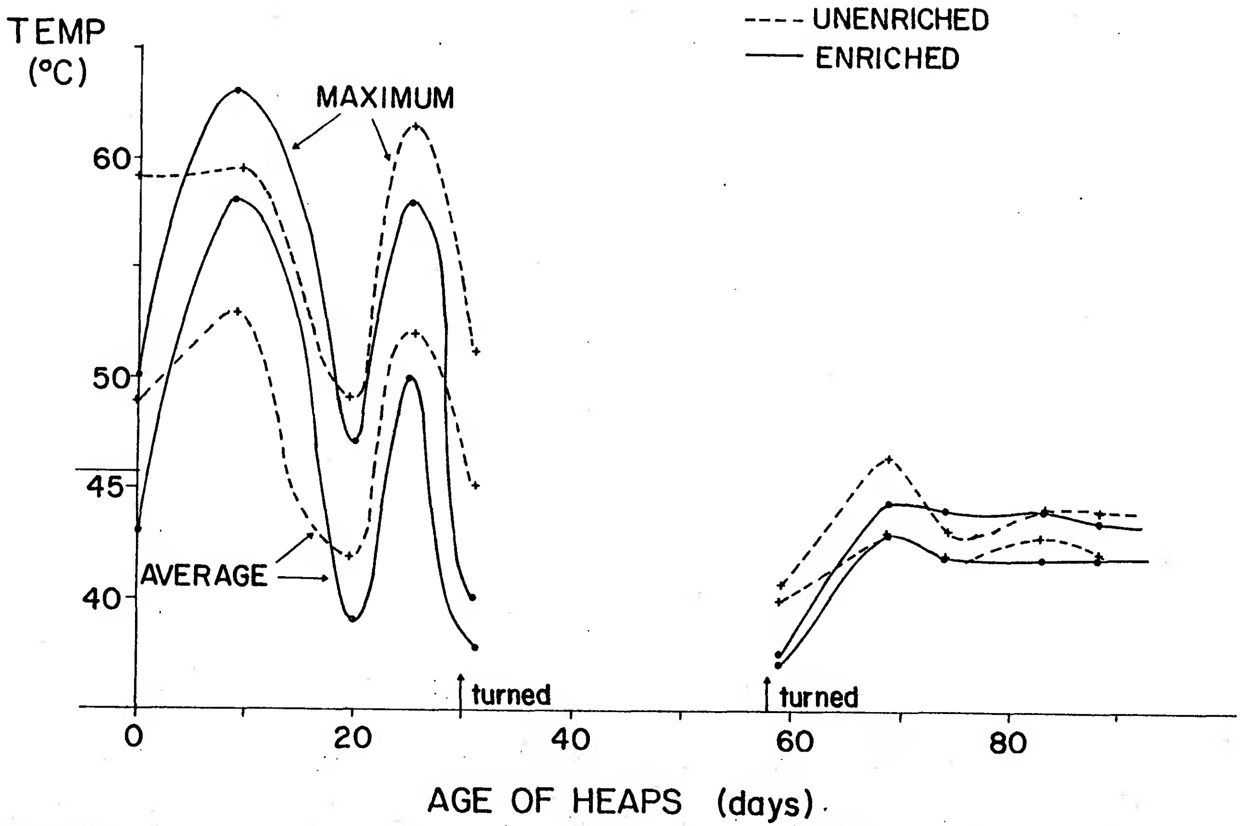


Fig. 7. Temperature in compost heaps, La Pacifica

for each of the three replicates. The individual readings varied with the depth and distance from the side of the heap as well, generally being highest in the center of the heaps and lowest in the corners and near the bottom. Similarly, as Atchley and Clark (1979) report, mesophilic sites or pockets were encountered even when overall temperature was high, and some spots consistently maintained higher than average temperatures. As they currently point out, this shows that there are not distinct mesophilic and thermophilic phases in composting. Rather, a mix of the two types of activity is always present, with one or the other predominating.

Temperatures in the compost heaps did not reach the high mean values of 60-70°C reported by others (Singley, Decker, and Toth, 1975; Galler and Davey, 1971). While several factors could prevent the temperature from reaching such high levels, aeration is probably the most critical in this case. Schulze (1960) found that a 10°C increase in temperature nearly doubles oxygen uptake, and Willson (1971) showed oxygen consumption rates as high as 1.12 ft^3 per minute per ton compost at temperatures of 35-62°C. Given the limited aeration provided by the technique used in Costa Rica, temperature is almost undoubtedly limited by oxygen uptake.

The relatively low temperature may be less indicative of the efficiency of the process than was once assumed, however. Finstein (1980) suggests, contrary to the popular belief that the compost heap should be maintained at as high temperature as possible, that even at 55°C excess metabolic heat begins to accumulate in the heap to a degree sufficient to inhibit growth of thermophiles. Similarly,

Bagstam (1978) found that the most rapid decomposition in a compost containing spruce bark occurred at 45°C, and that fungal and actinomycete populations declined at higher temperatures. Waksman, Cordon, and Hulpoi (1939) found that ammonia, which is easily lost, increased at 65°C and remained very high at 75°C, but reached trace amounts within only 19 days of composting at temperatures of 50°C, minimizing this loss. Thus, the temperatures maintained in Costa Rica may be near the optimum.

Where higher temperatures are desired, some improved method for ventilation would be required. This could be the case, for example, where farmers wish to apply the compost to vegetable crops and where, therefore, assuring maximum pathogen extinction is critical. Placing more vertical bamboo chimneys and adding one or more layers of horizontally placed chimneys could, perhpas, alleviate this problem. Overall, however, temperatures were sufficiently high to produce a stable product quickly. No pathogen counts were made.

A comparison of Fig. 8, showing nitrogen content (dry weight basis) over time in the heaps, and the graph of C:N ratios (Fig. 6) explains the apparent increase in carbon at about two weeks in six of the eight curves. There is, in fact, no way that significant additional carbon can enter the heaps unless fresh carbonaceous material is added, which did not occur. The apparent increase in carbon actually is due to a high loss of nitrogen during the first two weeks of composting.

Nitrogen can be lost easily from compost when it is present in either the nitrate (NO_3^-) or ammonia (NH_3) form, the former through

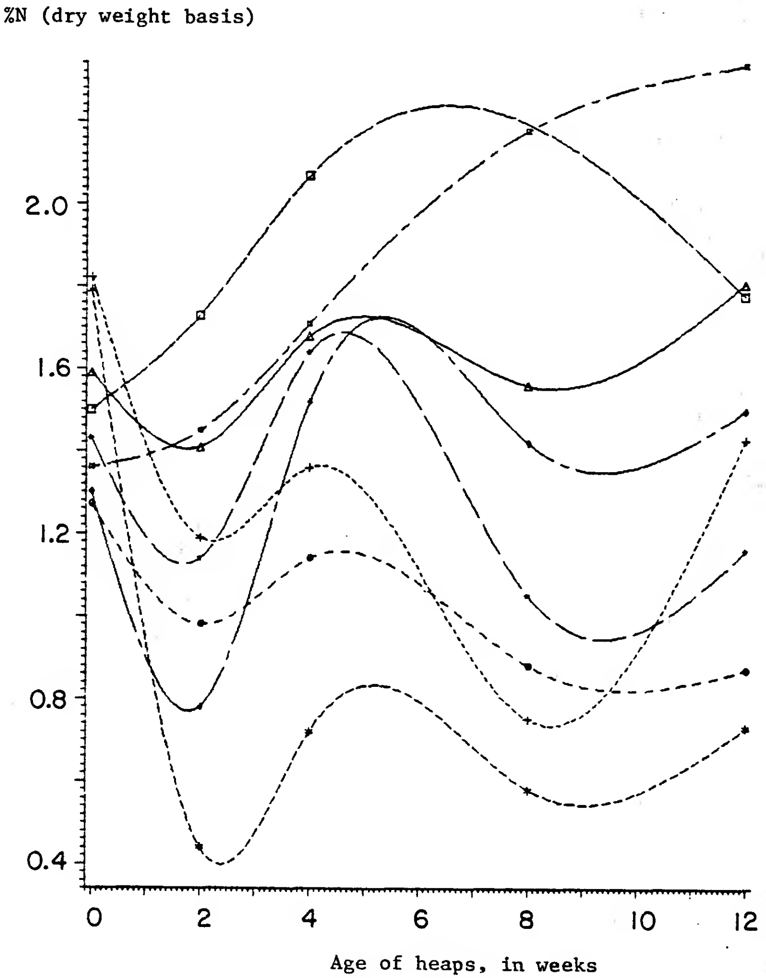
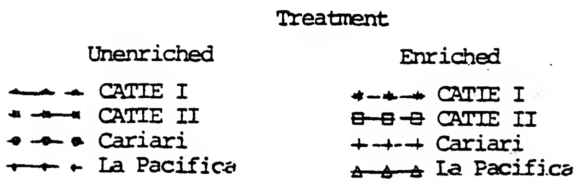


Fig. 8. N content of compost heaps.



leaching and the latter through escape into the atmosphere. In addition, Elliott, Schuman, and Viets (1971) have reported that organic nitrogen compounds enter the atmosphere from beef feedlot surfaces, and nitrites and nitrates can be reduced under anaerobic conditions and enter the atmosphere as nitrogen gas (Vanderholm, 1975). Several factors can cause such losses.

One possible cause of loss in this case was the low initial C:N ratios of the heaps. There is considerable disagreement over the optimal initial C:N ration for a compost heap. Golueke (1972) states that the optimum is 20:1 or 25:1, whereas Poincelot (1974) gives 26:1 to 35:1 as the optimum. In fact, the optimum initial C:N ratio will vary, depending on the types of materials being composted. The problem is to achieve a balance between nitrogen supply and available carbon. If the carbon is in a form that is very resistant to attack, a much higher C:N ratio is needed because only a portion of the total carbon is available as an energy source for the microorganisms (Regan and Jeris, 1970). A much lower C:N ratio is possible where more easily extractable forms of carbon are available. The problem is complicated even further by the differences in availability of nitrogen in various organic materials (Rubins and Bear, 1942; Toth, 1973).

Most authors also agree that a higher initial C:N ratio increases composting time (Waksman and Gerretson, 1931). However, the reported data do not clearly support the view of many authors (Golueke, 1972; Knuth, 1970; Poincelot, 1974; Taiganides, 1977) that a low initial C:N ratio necessarily or typically leads to higher levels of nitrogen

loss. Polprasert, Wangsuphachart, and Muttamara (1980) composted mixtures of leaves, water hyacinth, and nightsoil at initial C:N ratios of 20:1, 30:1, and 40:1. While those heaps with an initial C:N ratio of 30:1 or 40:1 showed a greater gain in total nitrogen (a 46% increase in total nitrogen) than the heaps with an initial ratio of 20:1 (a 10% increase in total nitrogen), the authors do not report any significant nitrogen losses. Similarly, Galler and Davey (1971) failed to find that nitrogen loss was greater in material with an initial C:N ratio of 21:1 than in that with a ratio of 43:1 composting poultry manure and sawdust.

The results found here are contradictory. The coincidence of high initial decreases in nitrogen content with low initial C:N ratio generally supports the view that this first episode of nitrogen loss was related to the original C:N ratio. Those heaps with the highest initial C:N ratios illustrated the least nitrogen loss in weeks one and two (Fig. 8) and do not illustrate the increase in C:N ratio at two weeks typical of the heaps with lower initial C:N ratios (Fig. 5). Nonetheless, as Table 15 shows, total nitrogen loss or gain, over the full process, was not necessarily related to initial C:N ratio.

Referring again to the graph of nitrogen content over time (Fig. 8), it will be seen that several heaps, especially those in the first trial at Turrialba (CATIE I) and those at Cariari, lost nitrogen well beyond the first two weeks. Table 15 shows that their total nitrogen loss was also high, and that it was lowest at La Pacífica. These data suggest that other mechanisms than the initial C:N ratio played

Table 15. Loss or gain of nitrogen in compost heaps.

Location	Treatment	Initial C:N Ratio	N Loss or Gain (%)
CATIE I	Unenriched	34:1	-27
CATIE I	Enriched	20:1	-35
CATIE II	Unenriched	30:1	+14
CATIE II	Enriched	20:1	0
Cariari	Unenriched	20:1	-22
Cariari	Enriched	17:1	-54
La Pacífica	Unenriched	22:1	+57
La Pacífica	Enriched	19:1	+59

a role in nitrogen loss. Even in the first two weeks, it was probably a combination of several factors rather than any single mechanism which produced the high nitrogen loss.

Inadequate aeration, already discussed above, was one problem. Poor aeration, in and of itself, limits biological activity. This is reflected in temperature, as described above, but the low level of microbiological activity also means that inorganic nitrogen begins to accumulate. As Knuth (1970) points out, inorganic nitrogen is subject to loss be several mechanisms. Nitrates, in particular, are apt to be lost by leaching.

Further, inadequate aeration is often accompanied by the onset of anaerobic conditions, or generally excessively high humidity, both of which occurred at Cariari and ar the first CATIE trial. Under these conditions, problems of nitrogen loss are exacerbated since nitrates are denitrified to nitrogen gas and lost. The high humidity further inhibits aeration, producing even more easily lost inorganic nitrogen.

Optimum moisture content for composting is generally considered to be 40 to 60% (Taiganides, 1977). Table 16 shows the moisture content of the compost heaps for the four trials. The heaps at both Cariari and those in the first trial at CATIE (I) maintained an average moisture content above the upper limit of 60% during composting, while those as La Pacífica and in the second trial at CATIE maintained acceptable humidity.

Willson and Hummel (1975) note that at moisture contents above 55% some anaerobic activity occurs. Further, at high moisture contents water replaces air, especially in the large pore spaces. Schulze's (1962)

Table 16. Average moisture content of compost heaps.

Location	Average Humidity (%)
CATIE I	70.4
Cariari	61.9
CATIE II	49.8
La Pacífica	50.2

data show that a minimum of 30% free air space should be maintained for aerobic composting. Free air space is affected both by bulk density, and by moisture content. Thus, at a bulk density of 400 g/l and moisture content of 60%, free air space remains adequate at 34%. But at the same bulk density and 70% moisture content, free air space drops to 27%. In compost heaps bulk density increases over time, so that moisture content becomes even more critical as the material approaches maturity. Schulze (1960) has also shown that oxygen uptake decreases slightly at a moisture content of 70%, even at low (20°C) temperatures. At higher temperatures with higher oxygen demand, this effect should be more pronounced. Anaerobic conditions were also noted at the CATIE I and Cariari trials. Poor aeration and excessive humidity were probably also important in nitrogen loss, then, in these two trials.

Another factor that can affect nitrogen loss is pH. Values of 6.0 to 8.0 are considered optimum for composting because most microorganisms exhibit greatest growth in that range (Willson et al., 1980). At lower pH values, bacteria, in particular, cannot survive well, but nitrogen loss due to ammonia volitalization increases with pH (Willson and Hummel, 1975), and the acceptable pH range is therefore limited. As Fig. 9 shows, the mean pH values in the four trials staued well within the accepted limits and should not have produced any negative effects. Even where pH was initially low (CATIE II), values rose very soon to near neutrality.

The pH values varied from heap to heap and did not conform to any of the general "patterns" of behavior that have been described.

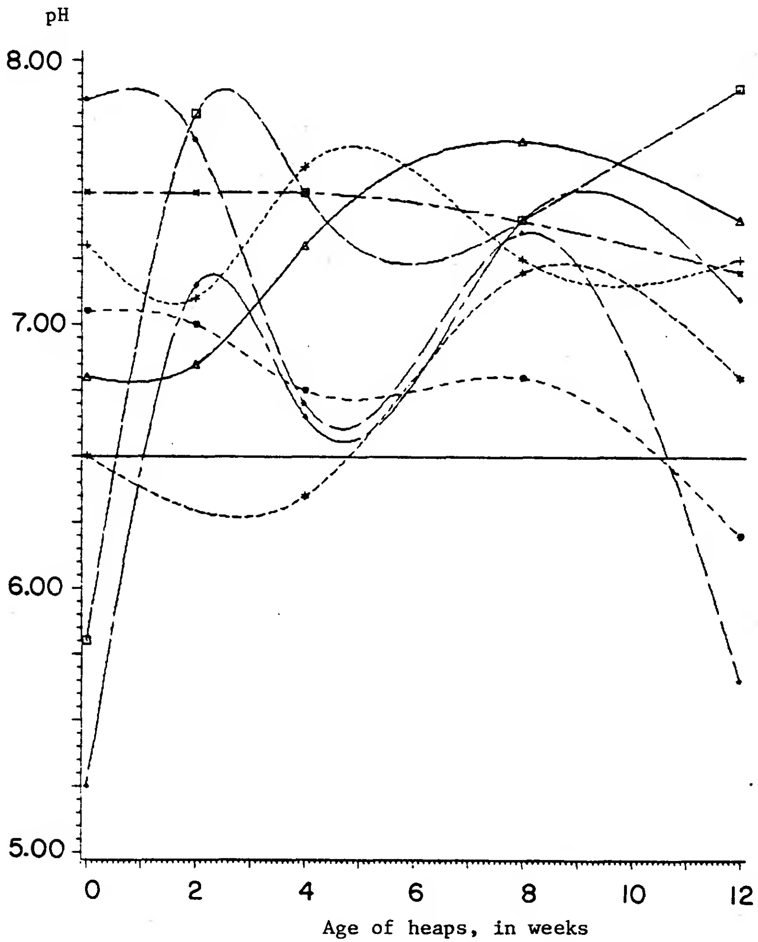


Fig. 9. Mean pH of compost heaps.

Treatment

Unenriched	Enriched
CATIE I	CATIE I
CATIE II	CATIE II
Cariari	Cariari
La Pacífica	La Pacífica

Regan and Jeris (1970) and Taiganides (1977), for example, state that pH values generally drop to about 5.0 in the early stages of composting, and then rise to 8.0 or 9.0 as the process terminates. Poincelot (1974) describes a similar sequence of values, but notes that finished compost is near neutral. These authors attribute the early acidity they noted to acid formation by bacteria. Willson (1971) and Willson and Hummel (1975), on the other hand, report contradictory trends, i.e., an initial increase in pH followed by a decline to near neutrality, while Suzuki, Harada, and Kumada (1975) and Schulze (1962) all report only very slight changes over time. As is generally true, pH samples must be taken from several points in a heap because pH, like temperature, is not uniform (Atchley and Clark, 1979) and failure to sample uniformly could explain some of these contradictory findings. All pH values are included in Appendix C, but no obvious trends are discernible from the individual values either.

In summary, the data indicate that nitrogen loss was related to initial C:N values, poor aeration, and excessive humidity. Total nitrogen loss was highest at high rainfall sites (CATIE I and Cariari) and initial C:N ratio varied strongly with nitrogen loss at these same sites. At lower rainfall sites, initial C:N ratio was less critical. Overall pH values fell within accepted norms at all sites.

In addition to nitrogen, retention of phosphorus and potassium are important in composting. Tables 47 through 54 (Appendix A) show the initial and final phosphate and potash contents for the heaps at the four trials and the concentration factor for each.[7] Analysis of

variance shows a significant difference in the concentration of phosphate for site but not for treatment (Table 17). In the case of potash, site, treatment, and the interaction effect were all significant (Table 18). Duncan's multiple range test shows that the concentration factor for phosphate at the second CATIE trial (2.67) was significantly higher than that at La Pacífica (1.55), the first CATIE trial (1.43), or the Cariari trial (0.88). The latter three sites did not differ significantly. In the case of potash, analysis of least significant difference between means reveals that for both unenriched and enriched compost, the first trial at CATIE resulted in significantly higher concentration factors than those at all other sites, and that at CATIE the concentration factor was significantly higher for unenriched than for enriched compost (See Tables 59 and 60, Appendix A). No other site exhibited differences in potash concentration.

The interpretation of these findings is somewhat unclear. The very high concentration factor for potash for the first trial at Turrialba (CATIE I) is repeated for other elements as well. Reference

[7]The concentration factor refers essentially to the percent concentration of a given element over time. It is derived by dividing the final concentration (in percent) of a given element by the initial concentration (in percent) of that same element. This factor was used for analysis because the heaps varied greatly in actual content of a given element both initially and at termination. This occurs because the manure, and vegetative material as well, differ in their elemental composition from one site to another. Thus, for example, final phosphate content varied significantly by site and treatment. However, this analysis does not reveal much information since initial phosphate content also varied by treatment and site. Concentration factors of less than one indicate overall loss of the given element.

Table 17. Analysis of variance, change in phosphate concentration in compost.

Source	df	Mean Square	F Value
Treatment	1	0.86	2.40
Site	3	3.41	9.51**
Interaction	3	0.85	0.11
Error	15	0.36	

Table 18. Analysis of variance, change in potash concentration in compost.

Source	df	Mean Square	F Value
Treatment	1	4.70	22.67**
Site	3	19.60	94.57**
Interaction	3	2.06	9.94**
Error	15	0.21	

to Tables 19 through 22 will show that the results of analysis of variance produced almost exactly the same results for aluminum, iron, zinc, and manganese. Tables 61 through 68 (Appendix A) show similar patterns for these elements when the least significant difference between means are examined as well. Further, as the partial table of correlation shows (Table 23), concentration of these elements was strongly correlated at the first CATIE trial, but not at other sites.

Few authors report microelement content of compost, so that it is difficult to compare these findings to others. Singley, Decker, and Toth (1975) do report the final content of some microelements in compost made of swine waste and urban garbage. They report final iron contents of 0.66% to 1.07%, compared to the 15.94% and 12.18% for unenriched and enriched heaps at CATIE (Group I, Table 47, Appendix A). At the other trials, the findings in Costa Rica are in line with theirs (see Tables 49, 51, and 53; Appendix A). Similarly, manganese contents in their compost ranged from 130 to 240 ppm, compared to 2,287 ppm for unenriched and 1.942 ppm for enriched heaps at CATIE. At CATIE, final copper content averaged 976 ppm for unenriched and 853 ppm for enriched heaps, whereas their values ranged from 8 ppm to 118 ppm. Average zinc content at CATIE was 4,713 ppm in unenriched heaps and 942 ppm in the enriched heaps--again compared to only 350 to 500 ppm for Singley, Decker, and Toth. These differences are even more surprising considering that the compost at CATIE did not incorporate urban wastes, which are normally higher than crop residues and animal manure in these elements.

Table 19. Analysis of variance, change in aluminum concentration in compost

Source	df	Mean Square	F Value
Treatment	1	1277.04	183.31**
Location	3	3187.47	457.55**
Interaction	3	1086.14	155.91**
Error	15	6.97	

Table 20. Analysis of variance, change in zinc concentration in compost.

Source	df	Mean Square	F Value
Treatment	1	363.21	6.21*
Location	3	950.15	16.24**
Interaction	3	247.33	4.23*
Error	15	58.49	

Table 21. Analysis of variance, change in iron concentration in compost.

Source	df	Mean Square	F Value
Treatment	1	2,496.10	80.59**
Location	3	12,591.14	406.53**
Interaction	3	1,532.63	49.48**
Error	15	30.97	

Table 22. Analysis of variance, change in manganese concentration in compost.

Source	df	Mean Square	F Value
Treatment	1	500.42	22.46**
Location	3	4,454.02	199.91**
Interaction	3	152.97	6.87*
Error	15		

Table 23. Partial correlation matrix, selected elements.

		Fe	Al	Zn	Mn
CATIE I	K_2O	.97	.92	.63	.90
CATIE II	K_2O	-.59	-.85	-.24	-.15
La Pacífica	K_2O	-.91	-.82	.41	.54
Cariari	K_2O	-.72	-.47	.13	-.03

Willson et al. (1980) report that composting both raw and digested sewage sludge reduced copper and zinc content. Copper content fell from 420 ppm in raw sludge and 725 ppm in digested sludge to 300 ppm in composts made from raw sludge and to only 250 ppm in that made from digested sludge. Zinc behaved similarly. This is difficult to explain since composting normally increases the concentration of non-volatile elements.

It is possible that potash, aluminum, iron, zinc, and manganese eneterd the first compost heaps at CATIE from outside sources. It is a commonly recommended practice to cover compost heaps with soil at the initiation of composting and after each turning. This practice was followed at the first CATIE trial until early analyses revealed a tendency toward high accumulations of aluminum and iron. At that time the practice was discontinued and it was not used at any other trial.

The soil at the CATIE test site is classified as a Typic Dystropept (Aste, 1971). It is high in iron, aluminum, and potash, as well as certain other microelements. The incorporation of this soil into the compost heaps could have resulted in the extremely high concentration of some of these elements in the final product. This hypothesis is supported by the extremely high concentration factor for iron and aluminum in the first CATIE trials, and by the very high total content of these elements in the finished heaps. Aluminum content reached 21.69% in the unenriched and 15.76% in the enriched heaps (dry weight basis) and iron content was 15.94% in the unenriched and 12.18% in the enriched heaps at maturity. Biological

processes alone would not account for either such high final contents of these elements, or for their high concentration over time.

The difference between response in unenriched and enriched heaps remains unexplained. They differed initially in potassium and phosphorus content, which was higher in the enriched heaps. Most other elements were initially lower in the enriched heaps because they contained less manure, which contributed the largest initial content of most elements. Tables 44, 45, and 46 in Appendix A show the content of these elements in the materials used in the compost. It was only in the first CATIE trials that any difference in concentration over time was due to treatment, for potash, aluminum, iron, zinc, and manganese. Copper also concentrated greatly over time at the first CATIE trials (Table 24), but no significant difference between enriched and unenriched heaps was found.

Retention of these elements in excessive amounts is not desirable because of the negative effects that they may exert on plant growth when present in large amounts. This is, of course, unlikely to be a problem in any given year, but with repeated application over many years build-up of heavy metals in the soil could possibly become a problem.

Retention of calcium and magnesium, which is very similar to the findings for final nitrogen content (Tables 25 through 27) can be explained as a function of climate. These plant nutrients are all susceptible to loss by leaching and the two high rainfall trials, CATIE I and Cariari, consistently illustrated little or no concentration of these elements over time, with the exception of the

Table 24. Analysis of variance, change in copper concentration in compost.

Source	df	Mean Square	F Value
Treatment	1	443.98	14.38**
Location	3	10,891.01	352.71**
Interaction	3	50.26	1.63
Error	15	30.88	

Table 25. Analysis of variance, change in calcium concentration in compost.

Source	df	Mean Square	F Value
Treatment	1	0.09	0.26
Location	3	1.94	5.74**
Interaction	3	0.17	0.50
Error	15	0.33	

Table 26. Analysis of variance, change in magnesium concentration in compost.

Source	df	Mean Square	F Value
Treatment	1	0.05	1.83
Location	3	0.40	15.83**
Interaction	3	0.16	6.32**
Error	15	0.03	

Table 27. Analysis of variance, final nitrogen content of compost.

Source	df	Mean Square	F Value
Treatment	1	0.01	0.00
Location	3	1.69	52.64**
Interaction	3	0.14	4.37
Error	15	0.03	

enriched heaps at Cariari, which concentrated magnesium as effectively as those at La Pacífica and CATIE II. Losses due to leaching of these elements is therefore probably the main factor affecting retention of these elements. Final calcium and magnesium values (Tables 47, 49, 51, and 53; Appendix A) were higher than those reported by Singley, Decker, and Toth (1975), who report 0.10% to 0.16% magnesium in finished compost and 1.55% to 2.25% calcium. Willson et al. (1980) report similar values to those found here for calcium; 1.4% in raw sludge compost and 2.0% in digested sludge compost, but they report no concentration over raw and digested sludge values as a result of composting.

Yield Response

At both Cariari and La Pacífica, significant differences in grain yield appeared (Tables 28 and 29). At Cariari, significant differences in corn stover and total biomass were also found (Tables 30 and 31), although not at La Pacífica (Tables 32 and 33). At the Turrialba study site, no significant differences resulted (Tables 34, 35, and 36) for reasons that are discussed below.

Further analysis of the data from La Pacífica and Cariari yields insights both into the advantages and disadvantages of the use of compost, and shows that locational differences, reflecting both differences in soil type and climate, can be expected to be encountered in the use of this type of organic fertilizer. Using Duncan's multiple range test, and testing for the least significant difference between means for the stover and total biomass data from Cariari,

Table 28. Analysis of variance, grain yield, Cariari.

Source	df	Mean Square	F Value
Treatment	4	836,360	3.74*
Farm	2	14,017,618	62.63**
Interaction	7	267,706	1.20
Error	10	223,815	

Table 29. Analysis of variance, grain yield, La Pacífica.

Source	df	Mean Square	F Value
Treatment	4	266,156	4.56*
Block	4	233,728	4.01*
Error	12	58,136	

Table 30. Analysis of variance, stover yield, Cariari.

Source	df	Mean Square	F Value
Treatment	4	9,843,333	5.81*
Farm	2	9,493,345	5.61*
Interaction	7	9,115,029	5.38**
Error	10	1,693,361	

Table 31. Analysis of variance, total biomass, Cariari.

Source	df	Mean Square	F Value
Treatment	4	15,736,639	9.08**
Farm	2	38,519,072	22.23**
Interaction	7	11,683,576	6.74**
Error	10	1,732,509	

Table 32. Analysis of variance, stover yield, La Pacífica.

Source	df	Mean Square	F Value
Treatment	4	8,573,439	2.93
Block	4	8,647,316	2.95
Error	12	2,928,886	

Table 33. Analysis of variance, total biomass, La Pacífica.

Source	df	Mean Square	F Value
Treatment	4	10,630,128	3.05
Block	4	11,433,762	3.28*
Error	12	3,486,909	

Table 34. Analysis of variance, grain yield, CATIE.

Source	df	Mean Square	F Value
Treatment	4	298,887	0.39
Block	3	540,619	0.71
Error	12	757,067	

Table 35. Analysis of variance, stover yield, CATIE.

Source	df	Mean Square	F Value
Treatment	4	605,060	0.44
Block	3	259,298	1.88
Error	12	1,377,996	

Table 36. Analysis of variance, total biomass, CATIE.

Source	df	Mean Square	F Value
Treatment	4	850,286	0.26
Block	3	4,588,536	1.38
Error	12	3,323,208	

where the interaction effect between farm and treatment was significant, reveals that the chemical and organic fertilizers behaved differently (Steel and Torrie, 1960) at the two sites.

At La Pacífica, the block effect is explained by differences in drainage. Rainfall was very high during the 1980-81 growing season at La Pacifica, even though the dry season was prolonged and delayed planting initially. Examination of the soil at the trial site indicated differences in drainage. Grey mottles were found within 25 to 35 cm of the soil surface in blocks four and five, and were located progressively deeper in the profile in blocks one, two and three. Excessive moisture was a problem during the trial and the more well drained blocks produced significantly higher yields than less well drained blocks. These results are shown in Table 79, Appendix B.

For corn grain yield, there were no significant differences between the plots treated by chemical, unenriched organic, and enriched organic fertilizer. However, analysis also shows that there were no significant differences between the unenriched organic, enriched organic, mixed chemical and organic, and zero treatment plots. The fact that the organically fertilized plots failed to differ significantly from the control indicates that the farmer is suffering some reduction in yield, compared to those obtained by applying equal quantities of chemical fertilizer, with the use of the organic form. At the same time, however, this reduction is not great enough for the organically treated plots to vary significantly from the chemically treated parcels (see Table 80, Appendix B).

Despite the differences in grain yield at La Pacífica, no significant differences in stover or total biomass yields were found at the 0.05 level. As the data show, overall yields were low and, in fact, area farmers suffered severe losses in the 1980-81 corn crop due to the extremely high rainfall. Four test plots were lost in the trial, due to a combination of flooding and poor weed control.

Analysis of the Cariari data is more complicated, largely because the trials were planted on three farms, each with different soil types. No interaction was present between farm and treatment in the analysis of variance for grain yield, although both factors were significant. As Table 81 (Appendix B) shows, results similar to those obtained at La Pacífica were found. At Cariari, however, the mixed chemical and organic, chemical, and enriched organic treatments showed the highest yields, and did not differ signficantly. Again, the chemical, enriched organic, and unenriched organic treatments failed to differ significantly. Overall, then, unlike La Pacífica, the mixed chemical and organic treatment gave the best results. Table 82 (Appendix B) shows that grain yield did vary significantly by farm, almost undoubtedly due to differences in native soil fertility.

Overall grain yield exceeded the normal yield for the area for those farmers who plant during the second growing season (August to December). The common practice is to plant in July or August (trials planted July 26, 28, and 30) and to apply approximately 42 kg nitrogen per ha, yield an average of 1.4 metric tons grain per ha (Meneses, 1979). Average yield here, for fertilized plots, was 1.6 metric tons per ha, applying 100 kg nitrogen per ha and increasing plant density

accordingly. In general, yields are higher during the first growing season (February to May) because there are fewer problems with pest control, rainfall is more reliable, and wind damage less likely.

Tables 83 through 86 (Appendix B) show the significant differences that were found for total biomass and stover yield by treatment and by farm at Cariari. These data are of relatively little interest here, since stover and biomass production are not critical production parameters to local farmers (stover is not used either as fuel, building material, or feed). Perhaps most interesting is the fact that all fertilizer treatments, but especially the use of chemical fertilizer, had a more pronounced effect on farm number two, where native soil fertility was lowest. Overall yields of grain were generally very low on this farm as well, and also showed the greatest response to fertilization of the three farms.

These data show that organic fertilizer alone failed to produce as high yields as those that resulted when chemical or combined chemical and organic fertilizer were applied. There are several possible explanations for these results.

First, even though the nitrogen in finished compost is generally considered to be readily available for uptake by plants, not all of the nitrogen in compost is in an inorganic form. Knuth (1970), for example, found that large amounts of inorganic nitrogen accumulate even during the early stages of composting, although Poincelot (1974) states that nitrate begins to accumulate only after 100 days, with significant buildup after 120 days. Nonetheless, despite this buildup of ammonium and nitrate nitrogen, Taiganides (1977) estimates that

the nitrogen in finished compost has an availability of only 50 to 70% that of ammonium sulfate. Tsukada, Sugihara, and Deguchi (1966) found, on the other hand, that only about 18% of the nitrogen in finished compost was in a form unlikely to become readily available to plants, although not all of the nitrogen was in an inorganic form initially.

As this discussion shows, it is difficult to determine the availability of compost nitrogen. As described previously, the plots treated with compost received 100 kg nitrogen, based on nitrogen content of the compost as determined by the Kjeldahl method. Not all of this nitrogen was immediately available in a form useable by plants, and some of the nitrogen was probably not mineralized during the growing season. The somewhat lower yields may therefore be explained by a lower <u>effective</u> nitrogen application rate on the organically treated plots.

Mathers and Goss (1979) have developed an equation to estimate the amount of fresh animal waste that must be used to supply any given desired nitrogen level for crops over a 20 year period. They suggest that 200 kg total nitrogen in fresh dairy cattle manure (at 3.5% nitrogen content) or 500 kg total nitrogen in dry corral manure (at 1.0% nitrogen content) would be needed to supply 100 kg nitrogen to plants in the first year after application. Turner (1975), using a different formula, suggests applying 685 lbs nitrogen per acre the first year and 540 lbs per acre nitrogen the second year for corn silage production in order to supply 175 lbs nitrogen per acre.

These figures are probably too high as estimates of appropriate compost application rates because more of the nitrogen in compost is readily available. Nonetheless, they do illustrate the degree to which this factor may vary.

Wolf (1977) reports that farmers in the northeastern United States apply about 8.2 tons manure per year on organically managed farms and about 9.1 tons per year on conventional farms for corn grain production. Nicolaides (1980) applied 10 metric tons per ha of several types of compost in Yurimaguas, Peru, and obtained corn yields similar to those on plots receiving complete mix fertilizer. He estimates that the composts supplied about 240 kg nitrogen per ha. In a recent publication, Willson et al. (1980) give the formula:

$$\% \text{ Available N} = 0.1 \times \% \text{ Organic N}$$

to estimate the nitrogen available to crops in the first growing season after compost application. No uniform guidelines for applying organic fertilizer, and especially compost, are available.

A second cause for lower yields could be the immobilization of soil nitrogen by microorganisms. This effect can result if high C:N ratio or poorly decomposed material is added to the soil. Regan and Jeris (1970) point out, however, that even high C:N ratio compost will not normally immobilize soil nitrogen if it is well decomposed, which the material in Costa Rica was.

Taiganides (1977) suggests, however, that total nitrogen content is equally important and found that the final product should have a nitrogen content of at least 1.2 to 1.5% to avoid immobilization of soil nitrogen. The compost at La Pacífica had a nitrogen content

well within or above this range. That applied at Cariari, however, fell below Taiganides' suggested minimums, especially the unenriched compost, which averaged only 0.92% nitrogen for the three Cariari farms. It is the unenriched organic fertilizer which yielded the lowest on the three farms as well. On the other hand, at La Pacífica where the overall nitrogen content averaged 1.60% for the enriched and 1148% nitrogen for the unenriched compost, these fertilizers produced yields that ranked second and third, respectively, after chemical fertilizer in yield. Data from soil tests, presented below, also show that soil nitrogen levels were depressed after application of the compost at Cariari, but were not at La Pacífica. In summary, while the degree of decomposition of the compost may have been adequate, and while the C:N ratio of the final product was low and stable, the low total nitrogen content of the compost applied at Cariari was a probable cause for the lower yields obtained on the compost treated plots at that site. The low total nitrogen content, in turn, was a direct result of producing the compost with a low-level technology at a high-rainfall site, as discussed previously.

These results do not indicate that it is of no value to use organic fertilizer under these conditions. The highest yielding plots at Cariari were those where both chemical and organic fertilizer were applied. This result is predictable in the sense that the advantages of both are utilized. That is, the chemical fertilizer supplies plant nutrients immediately upon application and the organic material continues to supply nutrients for some time. Tisdale and Nelson (1975) show that most nitrogen that becomes available from organic sources

does so within about three weeks, and that mineralization is virtually complete within fifteen weeks. Other authors (Djokoto and Stevens, 1961a, 1961b; Turner, 1975; Wallingford et al., 1975), however, have found that plant nutrients are released over a much longer period of time. Further, Chakravorti (1979) found that leaching of both urea and ammonium sulfate was reduced by blending these materials with organic materials such as seed hull cake, and even more so by mixing with compost. Thus, in addition to the slow release effect of the compost itself, its use with inorganic nitrogen may retard leaching loss of the chemical nitrogen source. Both of these factors can be expected to be important in an area of high, almost daily, rainfall, like Cariari, especially since soil texture on the three farms was loamy to a sandy loam.

At Turrialba, it was necessary to lime prior to planting. Because no lime spreader was available, this was done by hand, which resulted in a very uneven distribution of lime on the test plots. The land was then plowed to try to correct this condition, but no bottom plow was available, nor was a disk. As a result, the condition was not corrected. Variation in pH was very high both within and between plots at the time of planting and almost undoubtedly overshadowed any effect due to fertilizer application (Table 87, Appendix C).

Effects on Soil Chemical Characteristics

The various treatments produced differing effects on soil chemical properties. Organic matter content, pH, and macroelement and microelement content at four sampling dates are described and discussed below.

Figures 10, 11, 12 show the pH values of the soil solution over four sampling dates. Some chemical fertilizer, superphosphate, was applied to all plots, including the organically treated plots, in order to equalize nitrogen, phosphorus, and potassium levels, as explained in the section of this document dealing with materials and methods. As the curves show, those plots where only chemical fertilizer was applied experienced a severe decline in pH in the period immediately following fertilizer application. This same trend appears in the mixed organic and chemically treated plots. In those plots receiving all nitrogen from organic fertilizer, however, this tendency is much less pronounced, illustrating that the high cation exchange capacity of the organic material buffers the extremely acidic reaction of the super phosphate.

Results of analyses of variance for nitrogen, phosphorus, and potassium are shown in Tables 37, 38, and 39 for the three sites. Total nitrogen did not vary as a result of treatment at any site, although at Cariari and CATIE it did vary with sampling date. As Figs. 13, 14, and 15 show, soil nitrogen behaved differently at the three sites. At Turrialba, all fertilized plots show similar curves for nitrogen content. At Cariari, however, the plots receiving chemical fertilizer and those receiving unenriched organic fertilizer show peaks of soil nitrogen at 45 days, whereas the plots with mixed chemical and organic fertilizer and enriched compost do not. Further, as noted previously, soil nitrogen levels were depressed after fertilizer application on the organically treated plots, probably due to the low total nitrogen content of the fertilizer. Finally, at La

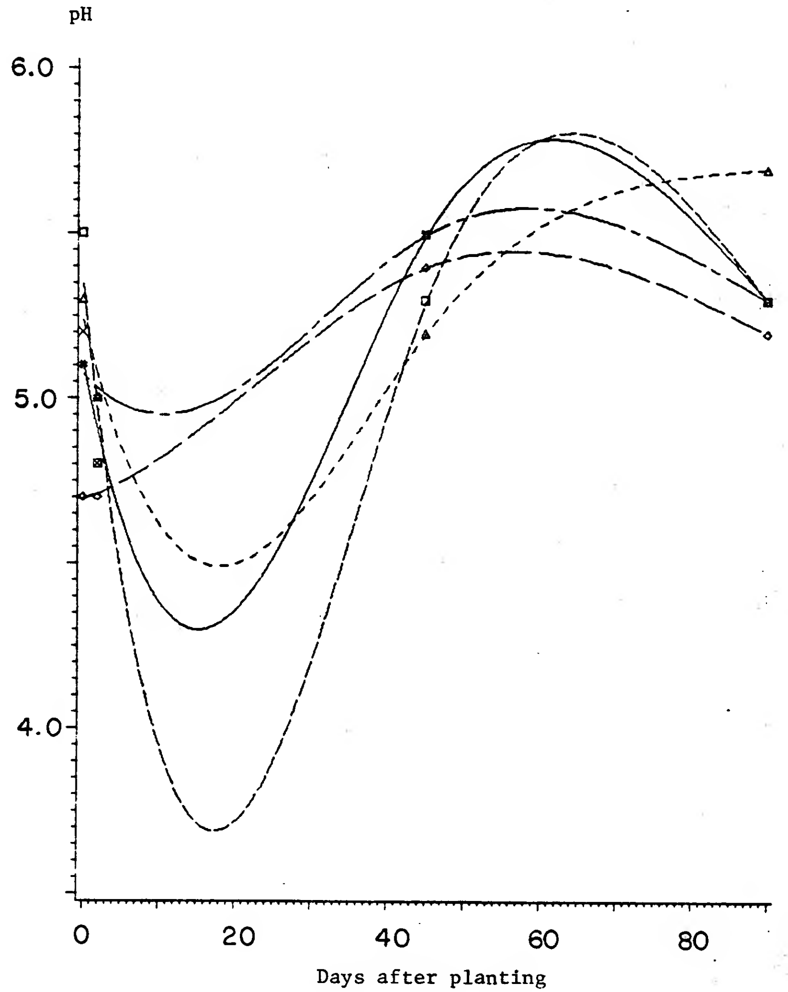


Fig. 10. Soil pH, CATIE.

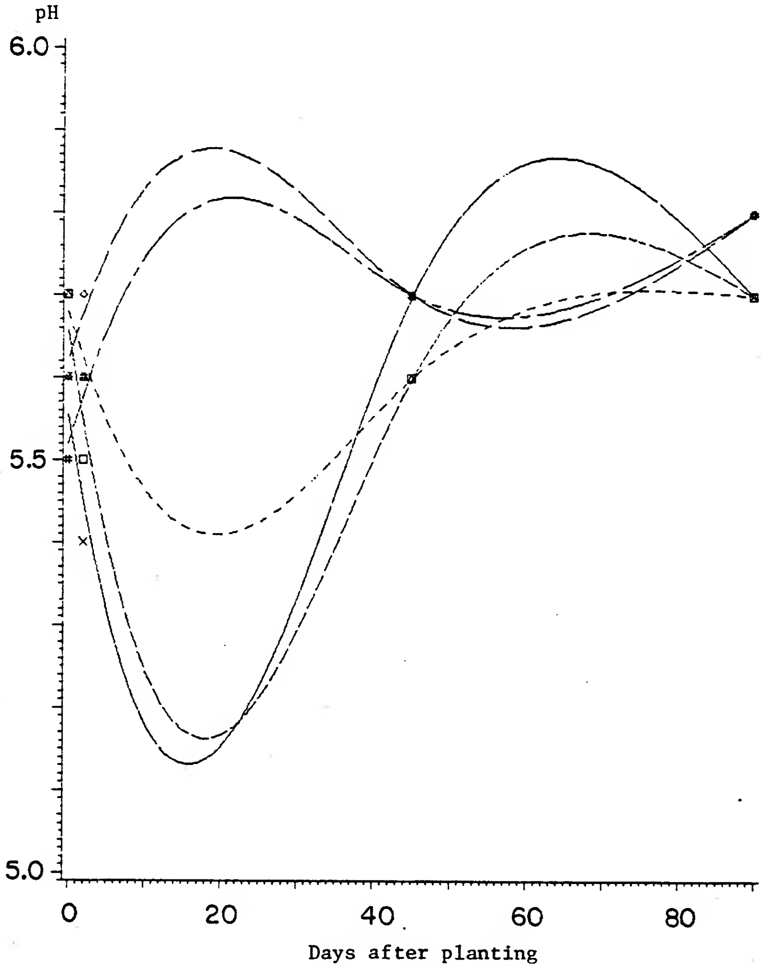


Fig. 11. Soil pH, Cariari.

Fertilizer Treatment

Unenriched Organic
Combined Chemical and Organic
Control
Enriched Organic
Chemical

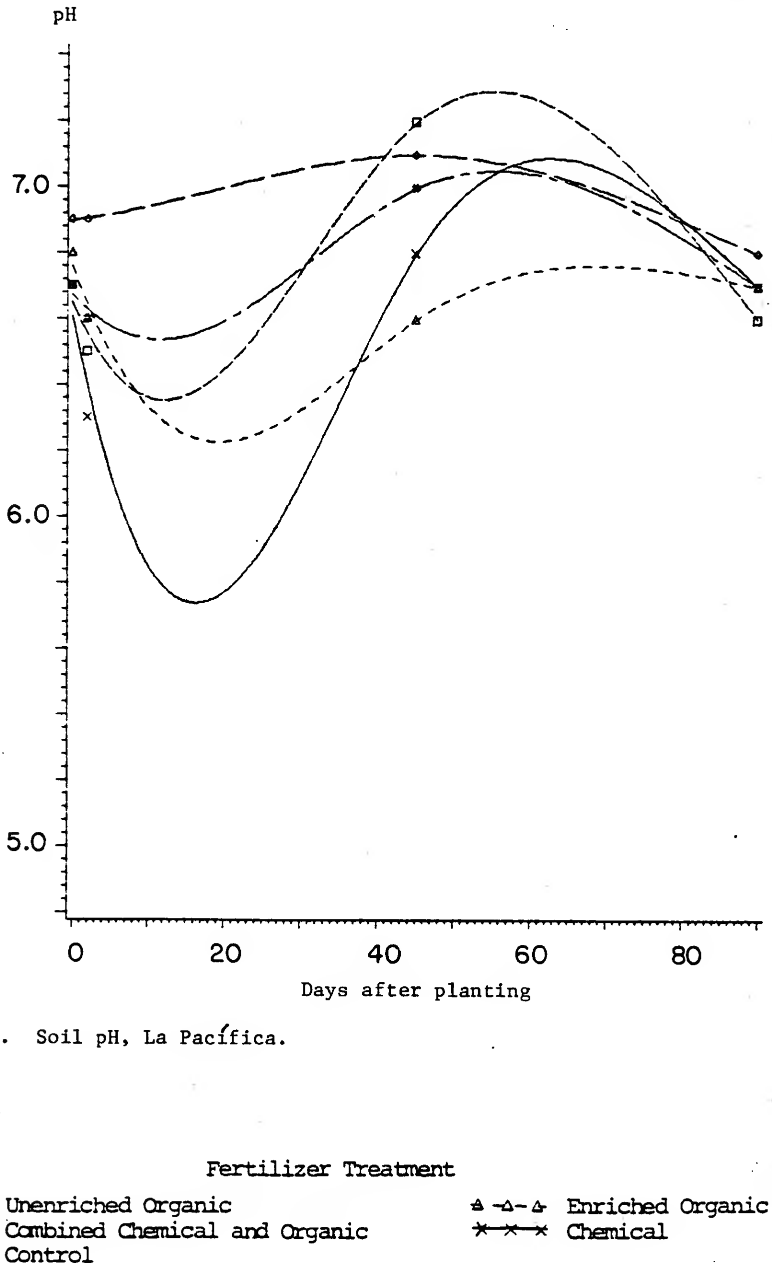


Fig. 12. Soil pH, La Pacífica.

Table 37. Analysis of variance, soil nitrogen, Cariari.

Source	df	Mean Square	F Value
Treatment	4	0.02	1.49
Time	3	0.04	3.13**
Farm	2	0.10	7.56**
Time X Treatment	12	0.01	0.69
Time X Farm	6	0.01	0.88
Treatment X Farm	8	0.03	1.99
Error	81	0.012	

Table 38. Analysis of variance, soil nitrogen, Turrialba.

Source	df	Mean Square	F Value
Time	3	0.001	5.93**
Treatment	4	0.0001	2.44
Block	3	0.0003	2.10
Time X Treatment	12	0.0002	0.86
Time X Block	12	0.0008	4.01**
Treatment X Block	9	0.0001	0.80
Error	35	0.0002	

Table 39. Analysis of variance, soil nitrogen, La Pacífica.

Source	df	Mean Square	F Value
Time	3	0.014	2.73
Treatment	4	0.003	0.74
Block	4	0.007	1.31
Time X Treatment	12	0.004	0.81
Time X Block	12	0.005	0.96
Treatment X Block	16	0.005	1.02
Error	46	0.005	

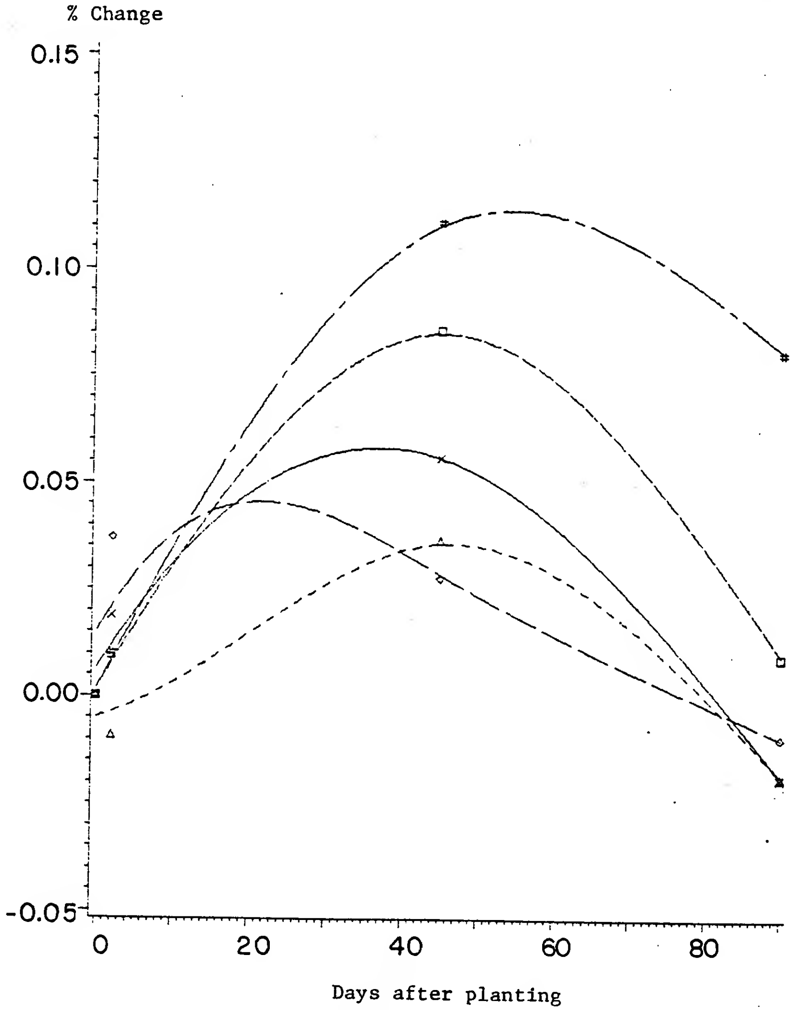


Fig. 13. Change in nitrogen content of soil, CATIE.*

Fertilizer Treatment

- Unenriched Organic
- Combined Chemical and Organic
- Control
- Enriched Organic
- Chemical

*Time effect significant at 0.01 level.

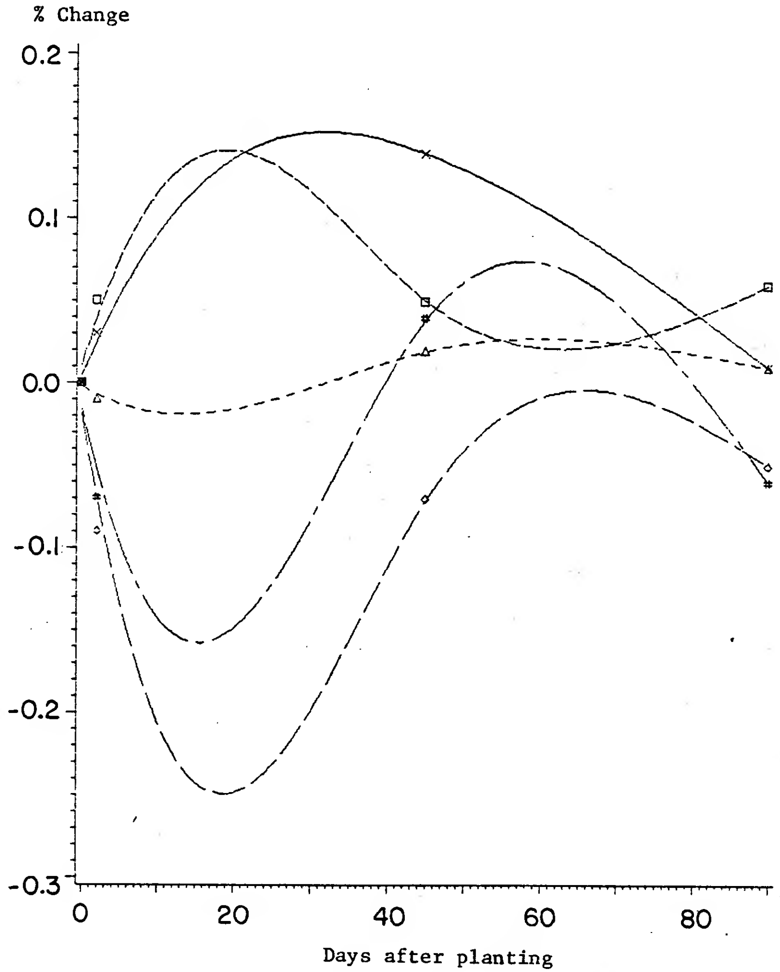


Fig. 14. Change in nitrogen content of soil, Cariari.*

Fertilizer Treatment

Unenriched Organic
Combined Chemical and Organic
Control
Enriched Organic
Chemical

*Treatment effect significant at 0.05 level.

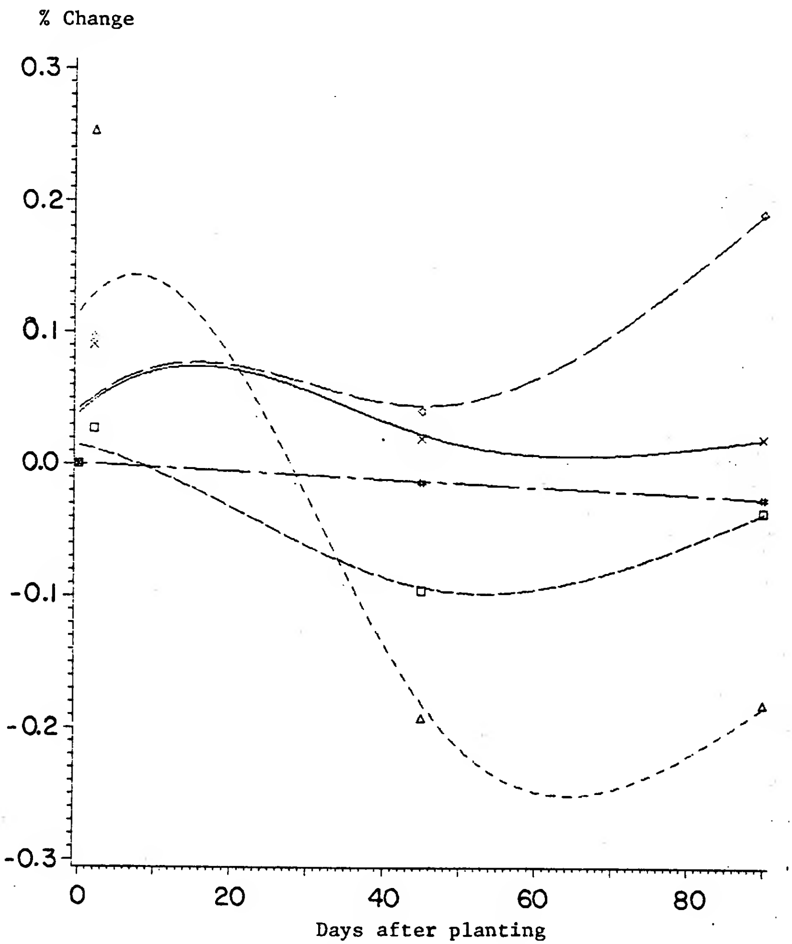


Fig. 15. Change in nitrogen content of soil, La Pacífica.*

Fertilizer Treatment

Unenriched Organic
Combined Chemical and Organic
Control
Enriched Organic
Chemical

*No significant effects at 0.05 level.

Pacífica the two organically fertilized plots show peaks in soil nitrogen that the other plots do not. This may be a result of the high rainfall experienced at that site, which would tend to remove chemically applied nitrogen by leaching. At both Cariari and Turrialba, soil nitrogen was significantly higher at 45 days after planting than at any other time.

Treatment did signficantly affect available phosphorus at La Pacífica and was significant for potassium at all sites. As Figs. 16, 17, and 18 show, the chemically treated plots and those treated with combined chemical and organic fertilizer show highest potassium levels at 2 and 45 days, after which differences between fertilizer treatments was very small. This reflects the fact that most or all of the potassium in the chemically treated plots was in an inorganic form.

The results of soil analyses for phosphorus are shown graphically in Figs. 19, 20, and 21. As these graphs show, at both Cariari and Turrialba, available phosphorus was highest with the combined chemical and organic fertilizer application, whereas the chemically fertilized plots showed highest available phosphorus at La Pacífica. These findings are probably related to the pH values of the three soils. The vertisol at La Pacífica has a near neutral pH value (see Fig. 12) and is not high in aluminum and iron, as the soils at Cariari and Turrialba are (Aste, 1971; Diaz-Romeu, 1978). At low pH values iron and aluminum become soluble and when they are active they fix phosphorus. A change of as little as 0.5 pH unit at low pH values affects phosphorus fixation (Copeland and Merkle, 1941). Thus, at CATIE and

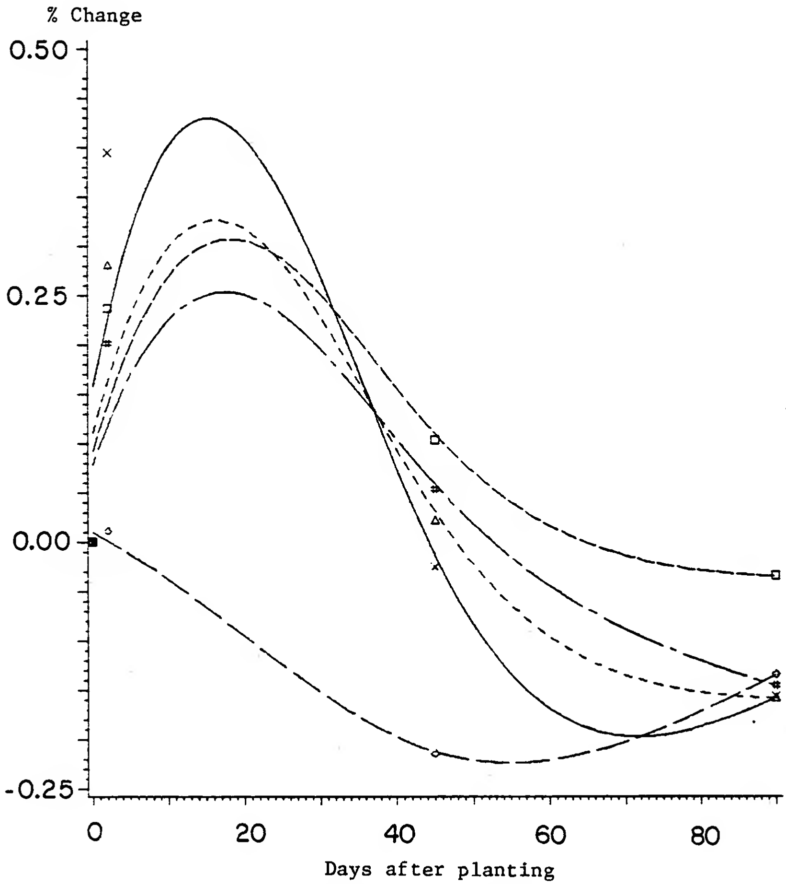


Fig. 16. Change in potassium content of soil, La Pacífica*

Fertilizer Treatment

Unenriched Organic
Enriched Organic
Combined Chemical and Organic
Chemical
Control

*Time effect significant at 0.01 level and treatment effect at 0.05 level.

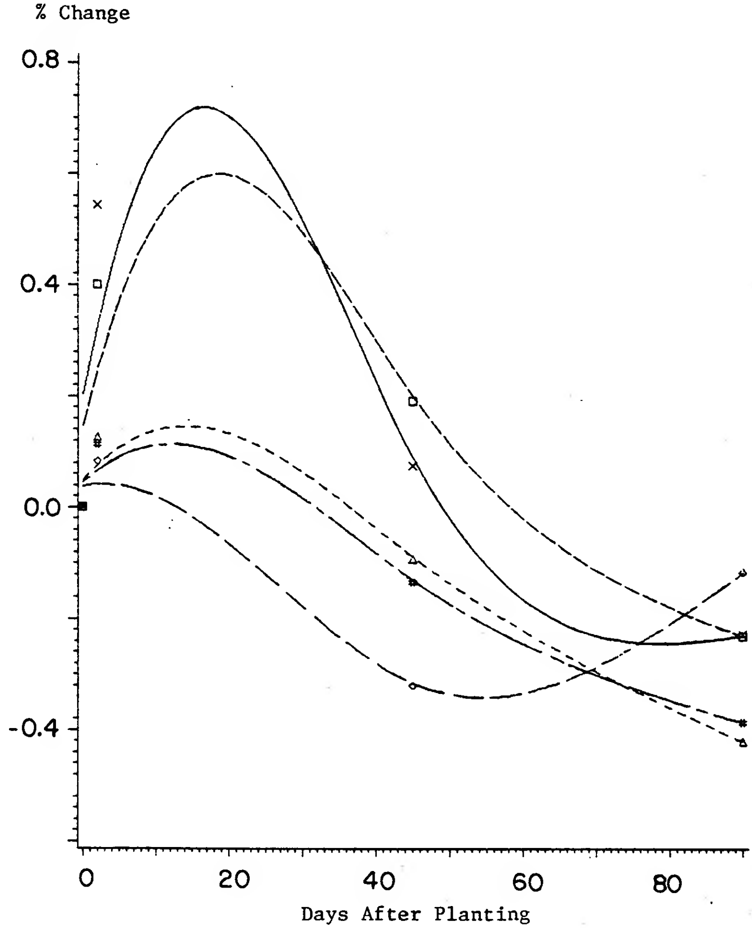


Fig. 17. Change in Potassium content of soil, CATIE*

Fertilizer Treatment

Unenriched Organic
Combined Chemical and Organic
Control
Enriched Organic
Chemical

*Time and treatment effects significant at 0.01 level

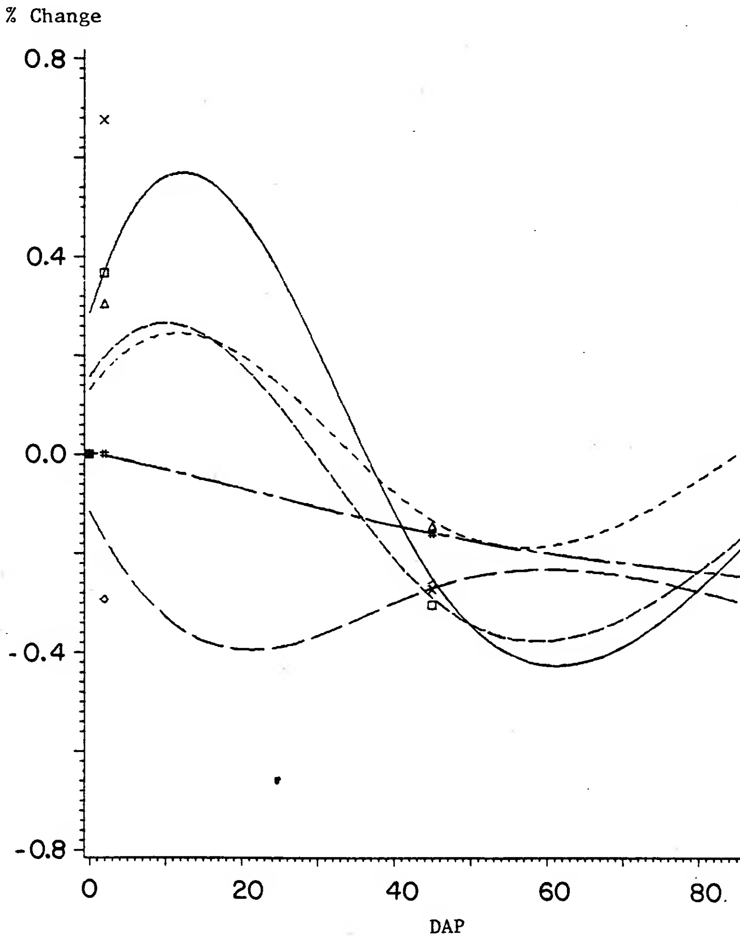


Fig. 18. Change in potassium content of soil, Cariari.*

Fertilizer Treatment

Unenriched Organic

Combined Chemical and Organic

Control

Enriched Organic

Chemical

*Time and treatment effects significant at 0.01 level.

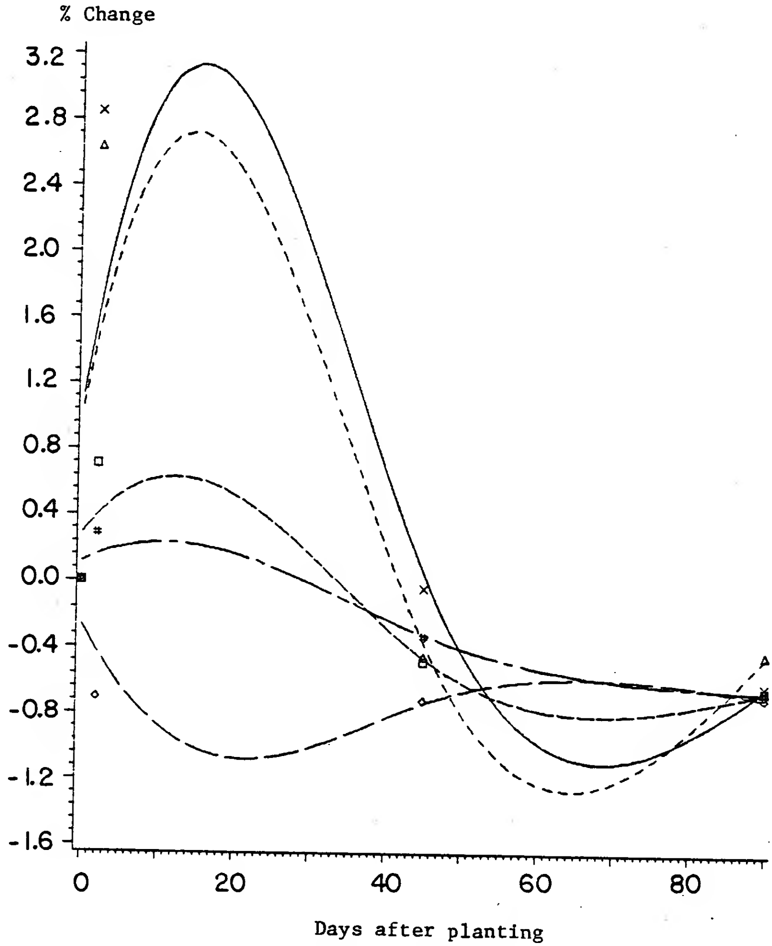


Fig. 19. Change in available phosphorus content of soil, La Pacífica.*

Fertilizer Treatment

Unenriched Organic
Combined Chemical and Organic
Control
Enriched Organic
Chemical

*Time and treatment effects significant at 0.01 level.

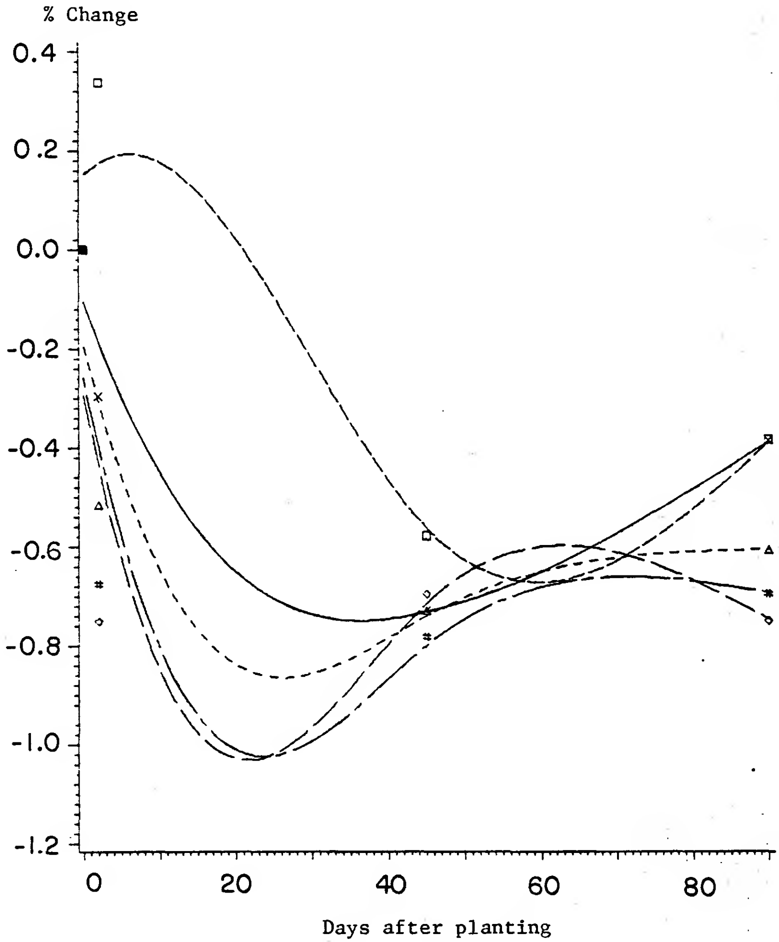


Fig. 20. Change in available phosphorus content of soil, Cariari.*

Treatment

Unenriched	Enriched
CATIE I	CATIE I
CATIE II	CATIE II
Cariari	Cariari
La Pacifica	La Pacifica

*Time effect significant at 0.01 level.

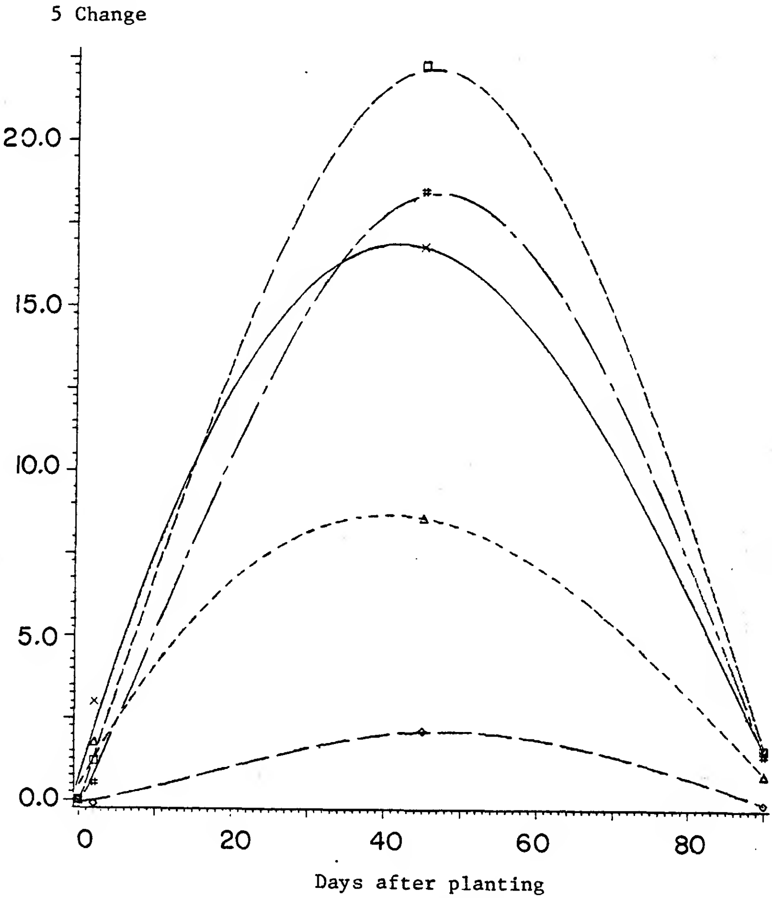


Fig. 21. Change in available phosphorus content of soil, CATIE.*

Fertilizer Treatment

Unenriched Organic
Enriched Organic
Combined Chemical and Organic
Chemical
Control

*Time effect significant at 0.01 level.

Cariari, where pH declined to low values after fertilization, phosphorus fixation was probably a problem. At La Pacífica values also fell, but since this soil has a high pH, phosphorus fixation should not be a problem at the values obtained. The chemical treatment at La Pacífica therefore significantly exceeded all other treatments except enriched organic in available phosphorus on day two. At other sites the inorganic phosphorus may have become unavailbable, so that no differences between treatments appear.

Several authors (Aslander, 1950; Dalton, Russell, and Sieling, 1952; Perrott, 1978; Singh and Ram, 1977; Singh, 1975; Vyas and Motiramani, 1971) have found that the addition of organic matter increases availability of inorganic phosphorus. Singh and Ram (1977) suggest that organic compounds chelate iron and render it relatively inactive in phosphorus fixation, and Perrott (1978) suggests that a similar mechanism is at work with aluminum. While there was no significantly higher phosphorus availability at Cariari and Turrialba, the graphs show that the combined chemical and organic treatment plots did have higher available phosphorus at those two sites. These data tend to support the view that addition of organic matter aids in phosphorus availability at low pH values and high aluminum and iron concentrations, but they are inconclusive.

Other authors (Mathur, Sarkar and Mishra, 1980; Sadaphal and Singh, 1979; Verma and Lamba, 1963; Walunjkar and Acharya, 1955) have also found that phosphorus is more available when it is incorporated into compost in an inorganic form, as was the case with the enriched compost. This finding was not generally supported here. At La

Pacifica, at day two, the enriched organic plots did show significantly higher available phosphorus than other plots. At other sites, however, it behaved no differently from other treatments.

Figures 22, 23, and 24 show the manganese content of the soil at the three sites. Even though the chemical fertilizer contained no manganese, which was present in the compost, available manganese was generally highest in the chemically treated plots, especially prior to 45 days. At La Pacifica (Fig. 22), manganese was also high in the mixed chemical and organic plots, but available manganese increased later than in the chemically treated plots. This period of higher availability of manganese was probably related to the decrease in pH values of the soil upon fertilization since manganese availability is affected very rapidly by decreases in pH (Gammon, 1976). The decrease in pH was more pronounced on the chemically treated and the mixed chemical and organic plots. The different trends may also have been a result of the effects of organic matter on manganese. Although manganese is not as subject to chelation by organic complexes as some microelements (Tisdale and Nelson, 1975), it does form relatively insoluble complexes over time. Velez-Romos and Standifer (1977) found that the addition of organic matter to submerged soils initially increased available manganese, but that at later dates available manganese declined more rapidly on plots where organic matter was added than on untreated plots. They found that organic matter had no effect on manganese availability at low moisture contents, however.

Copper is chelated much more readily than manganese by organic compounds (Tisdale and Nelson, 1975). Partly because of this,

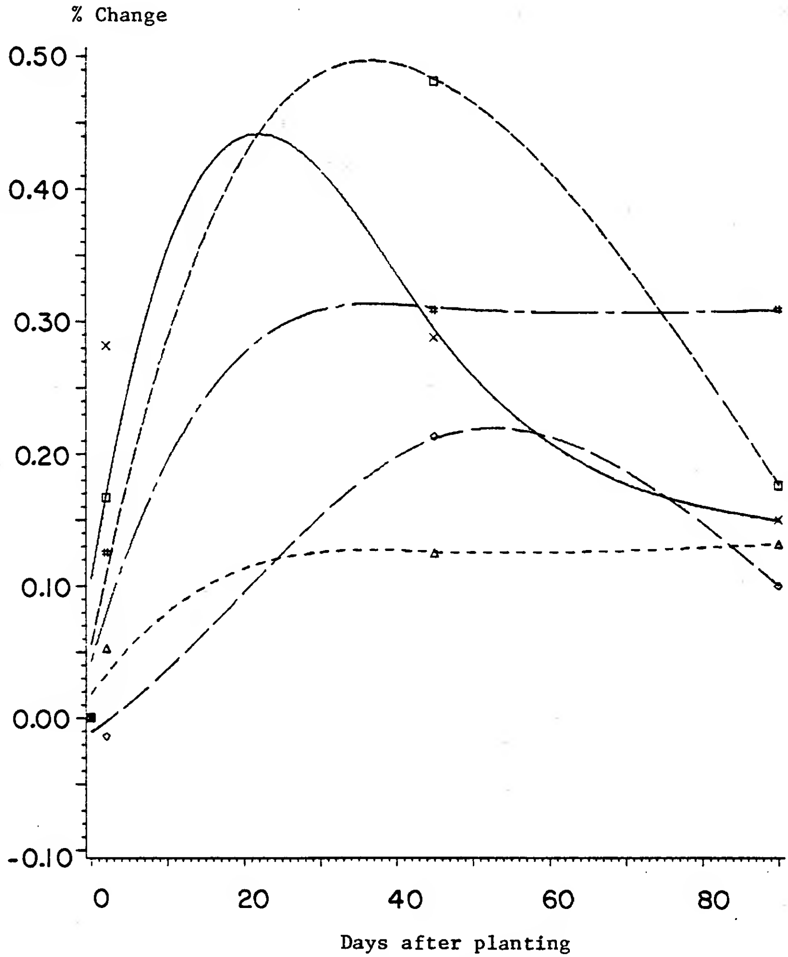


Fig. 22. Change in manganese content of soil, La Pacífica.*

Fertilizer Treatment

Unenriched Organic
Combined Chemical and Organic
Control
Enriched Organic
Chemical

*Time effect significant at 0.01 level.

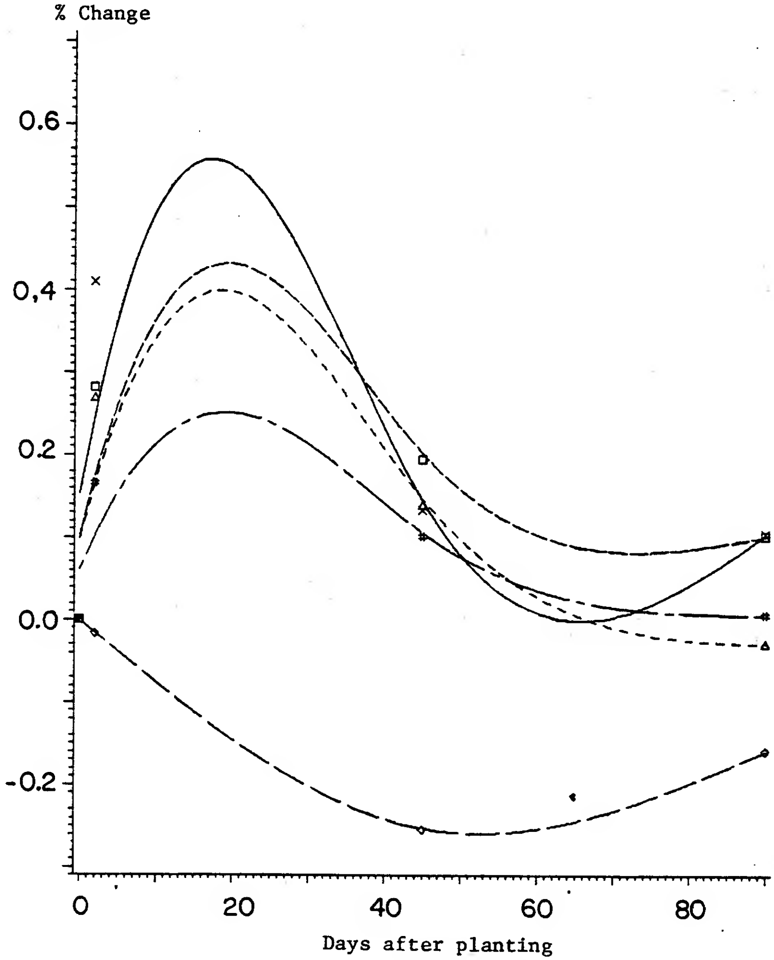


Fig. 23. Change in manganese content of soil, CATIE.*

*Time and treatment effects significant at 0.01 level.

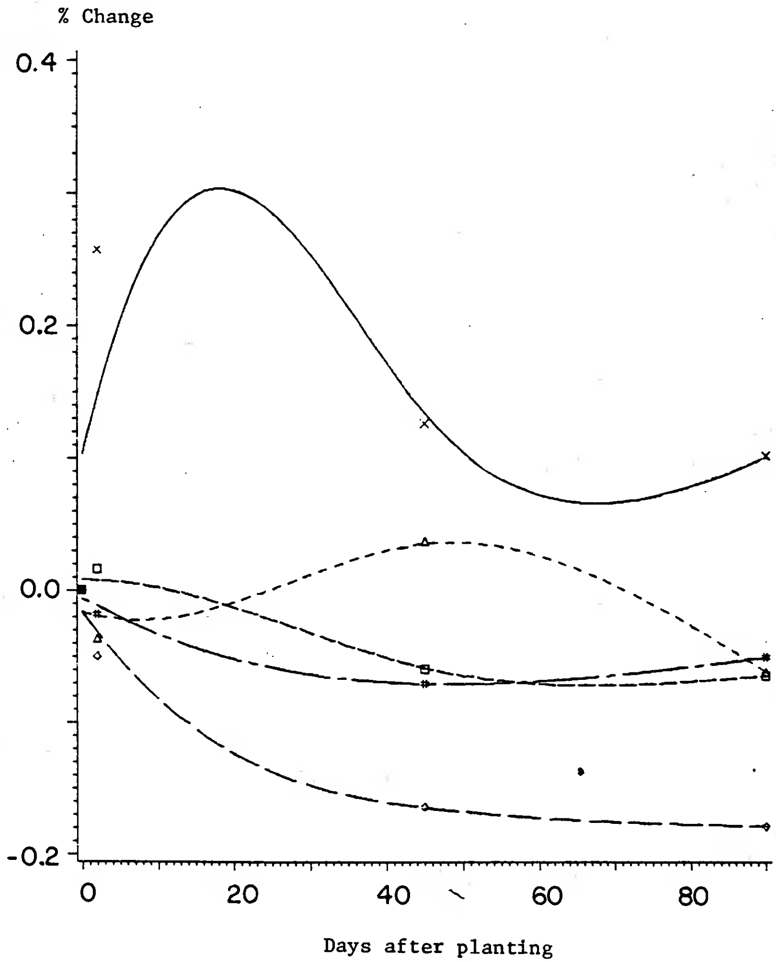


Fig. 24. Change in manganese content of soil, Cariari.*

Fertilizer Treatment

Unenriched Organic

Enriched Organic

Combined Chemical and Organic

Chemical

Control

*Time effect significant at 0.05 level and treatment effect at 0.01 level.

changes in pH do not affect copper availability as rapidly as manganese availability, but changes in organic matter content of the soil do have large effects (Gammon, 1976). Further, the activity of other metallic ions such as iron and aluminum also affect its availability (Tisdale and Nelson, 1975). These charactersitics are reflected in Figs. 25, 26, and 27. Treatments using organic fertilizer tended to show a greater response in copper availability than pure chemical treatments. At La Pacífica, where pH never declined to very low values, chemical treatment have very little effect on copper availability, whereas copper did become more available on organically treated plots, although only slowly. Changed in copper availability were less at Turrialba and Cariari, where pH may have been important as well. Greater effects of chemical treatment did appear at those sites.

Zinc is more available at low (less than 6.0) than high pH values, but does not respond to changes in pH as rapidly as, for example, manganese (Gammon, 1976). Deficiencies in plants have been observed on soils high in organic matter, probably because of the formation of relatively insoluble complexes (Tisdale and Nelson, 1975). At Turrialba and Cariari (Figs. 28 and 29), zinc tended to decrease in the first 40 days after planting, regardless of treatment. At La Pacífica (Fig. 30), zinc also decreased on the control plots, but showed a slight increase on both the organically and chemically treated plots. The reasons for these reactions are unclear, but apparently are tied to characteristics of the soils themselves.

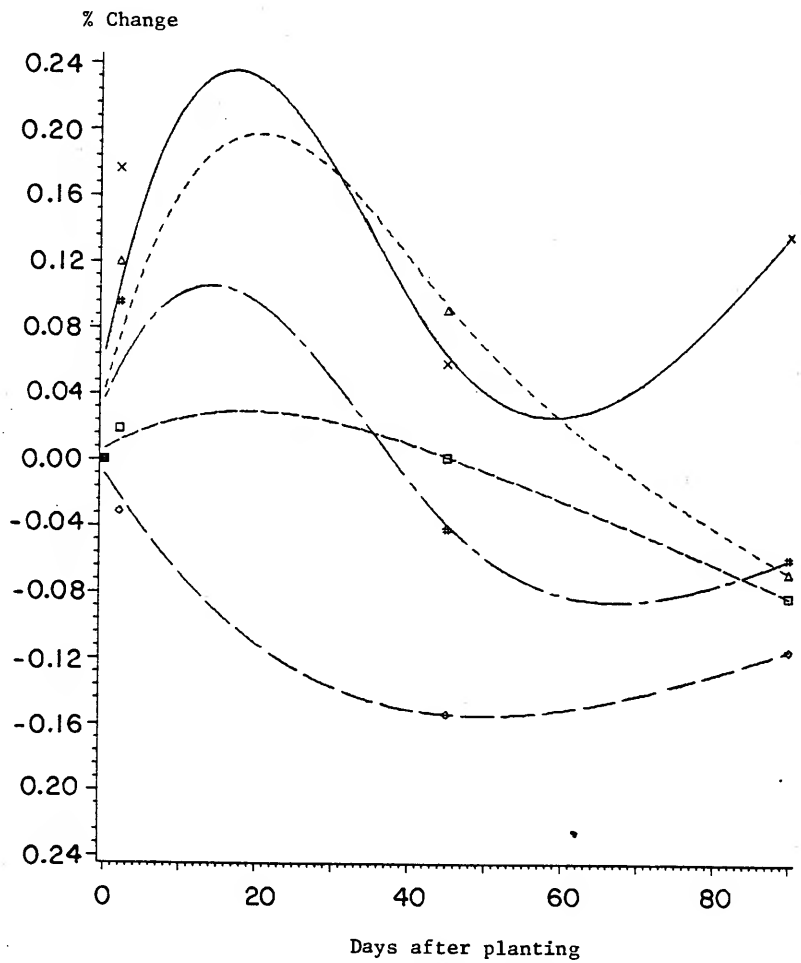


Fig. 25. Chnage in copper content of soil, CATIE.*

Fertilizer Treatment

Unenriched Organic
Enriched Organic
Combined Chemical and Organic
Chemical
Control

*Time effect significant at 0.05 level and treatment effect at 0.01 level.

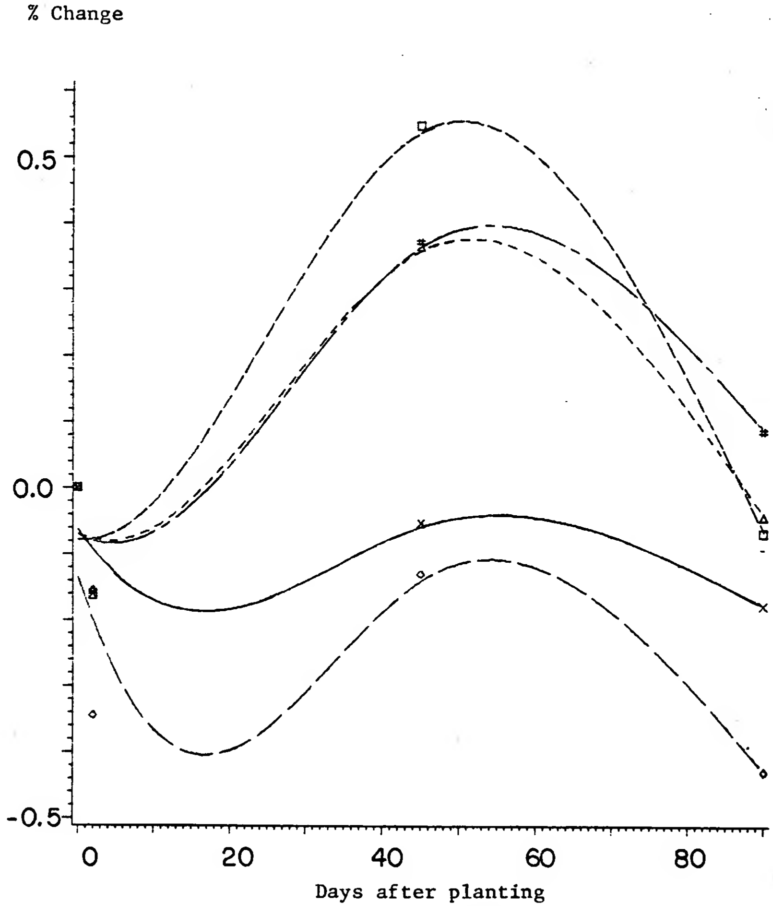
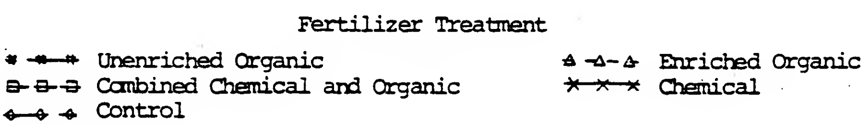


Fig. 26. Change in copper content of soil, La Pacífica.*



*Time effect significant at 0.01 level and treatment effect at 0.05 level.

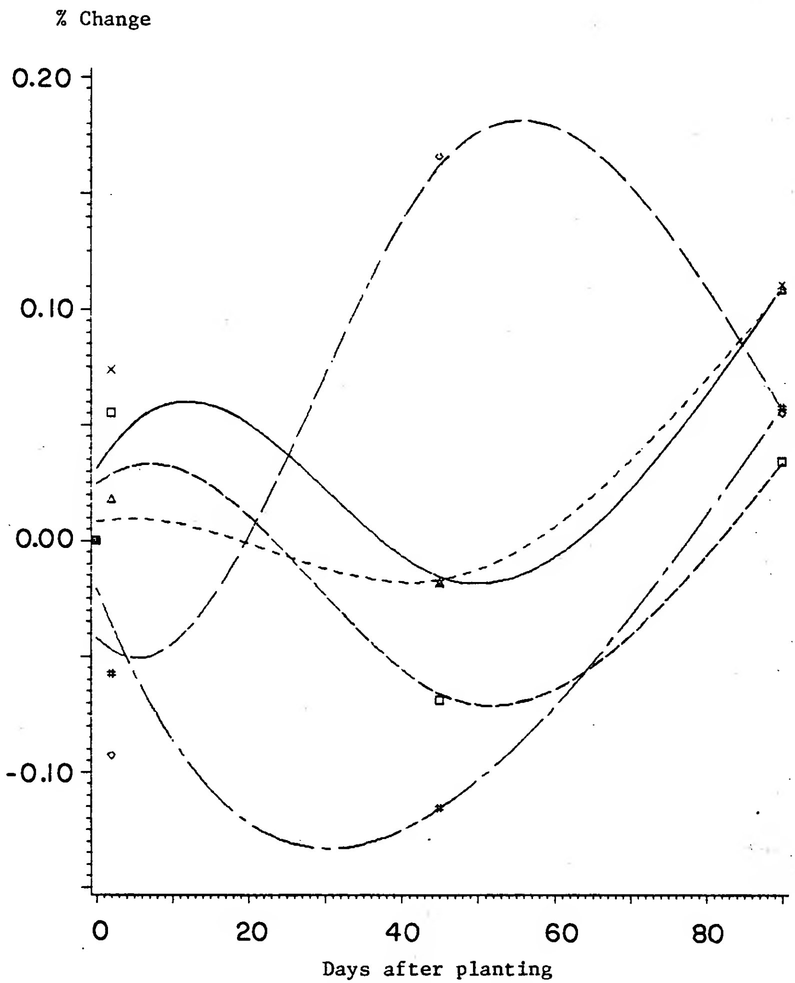


Fig. 27. Change in copper content of soil, Cariari.*

Fertilizer Treatment

Unenriched Organic
Combined Chemical and Organic
Control
Enriched Organic
Chemical

*No effect significant at 0.05 level.

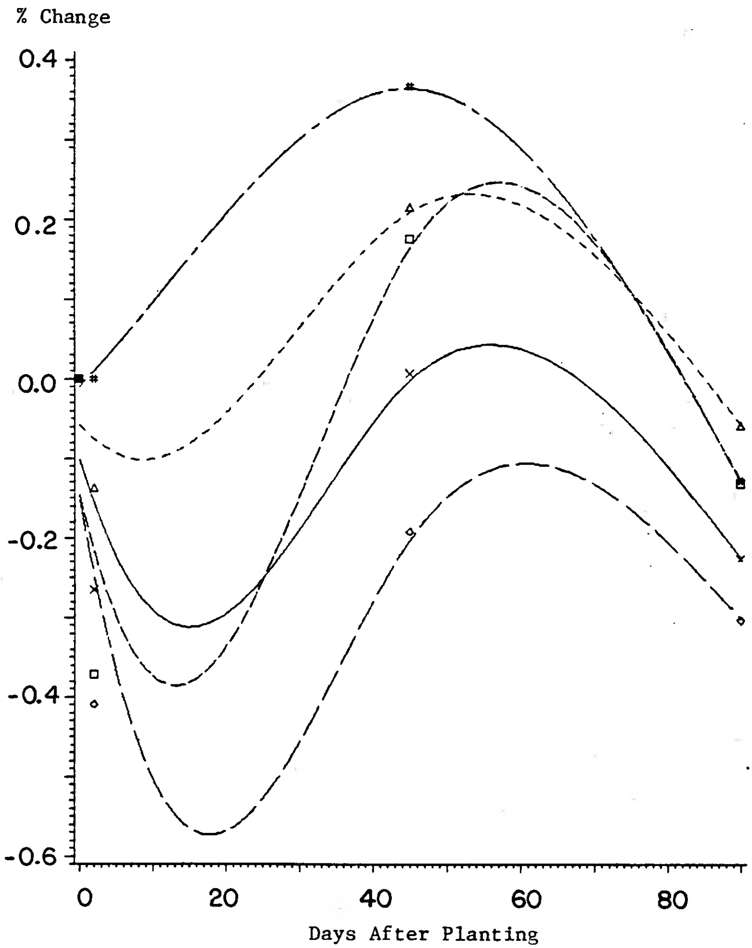


Fig. 28. Change in zinc content of soil, CATIE*

Fertilizer Treatment

Unenriched Organic
Combined Chemical and Organic
Control
Enriched Organic
Chemical

*Time effect significant at 0.01 level

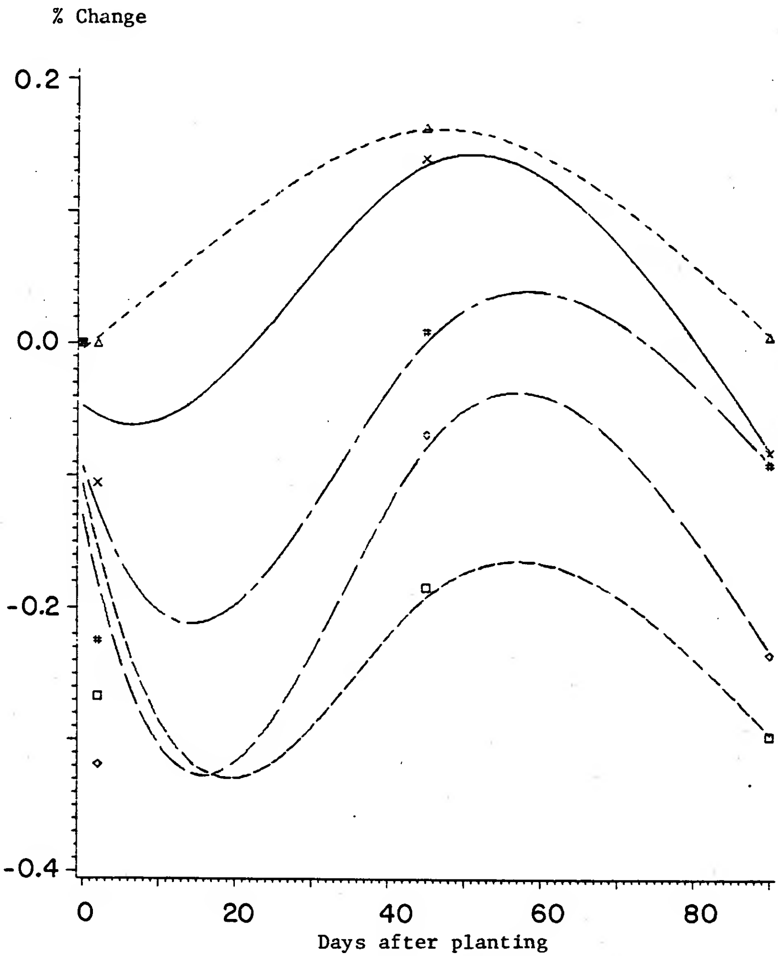


Fig. 29. Change in zinc content of soil, Cariari.*

Fertilizer Treatment

Unenriched Organic
Combined Chemical and Organic
Control
Enriched Organic
Chemical

*Time and treatment effects significant at 0.01 level.

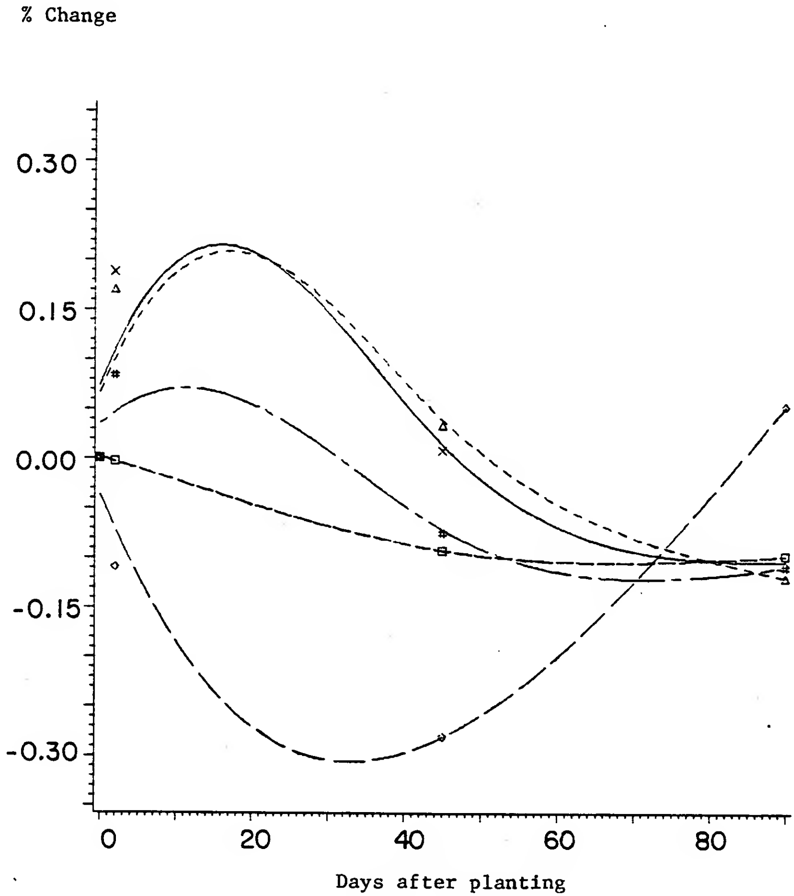


Fig. 30. Change in zinc content of soil, La Pacífica.*

Fertilizer Treatment

Unenriched Organic
Enriched Organic
Combined Chemical and Organic
Chemical
Control

*Time effect significant at 0.01 level and treatment effect at 0.05 level.

Iron content in the soil showed high initial increases at Turrialba (Fig. 31) and somewhat large increases at Cariari (Fig. 32), especially on chemically treated plots. Again, this is probably a result of the change in pH on these plots. At La Pacífica (Fig. 33), iron did become more available, but this occurred later, and was more pornounced on plots receiving organic fertilizer. The effects of the treatments, then, were similar to those for zinc and probably reflect similar processes at work. These two elements do respond similarly to change in pH and organic matter content of the soil (Gammon, 1976).

This discussion has, of necessity, been brief. The study was not intended primarily to examine the effects of fertilizer treatment on soil chemical properties. The results that were obtained do indicate that the entire area of effect of fertilizer treatment, especially the addition of organic matter, on microelement availability is an area where further research would be most fruitful. To date, microelement deficiencies have been observed only rarely on tropical soils. However, as these soils are more intensively cultivated for longer periods of time, microelement availability will become an increasingly important question and, as Greenland (n.d.) suggests, soil organic matter content could be a very important element in this regard.

Given the large quantities of organic matter that were added to the soil, especially on the plots receiving only unenriched or enriched compost, the effects were surprisingly small. As Tables 40, 41, and 42 show, treatment had a significant effect on soil organic matter content only at Cariari. At that site (Tables 88 and 89, Appendix C),

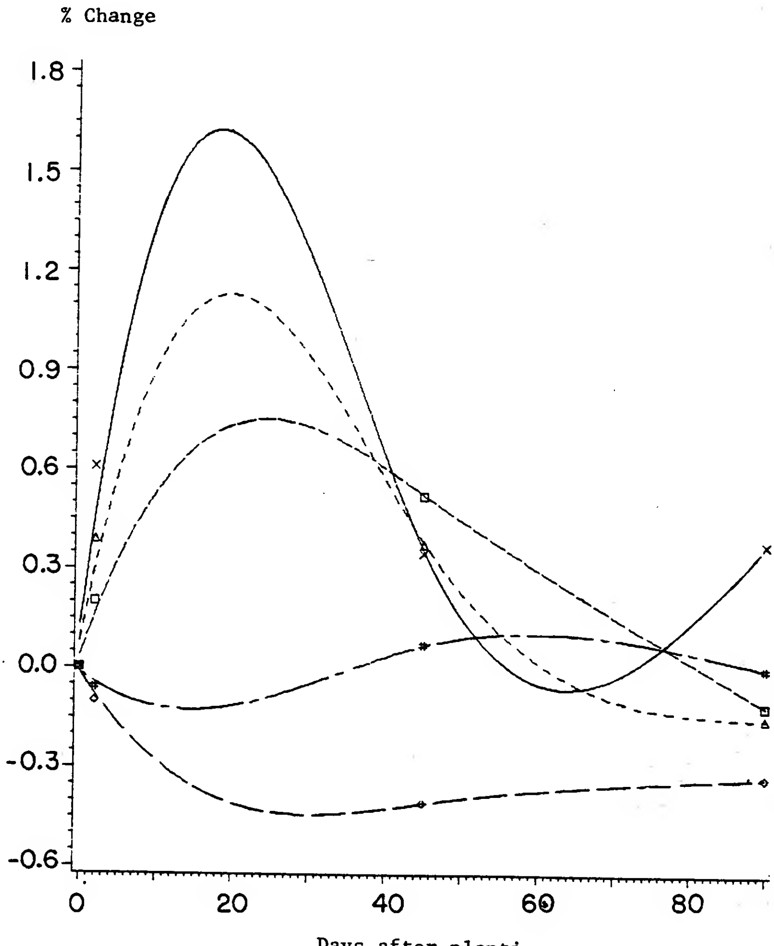


Fig. 31. Change in iron content of soil, CATIE.*

Fertilizer Treatment

Unenriched Organic
Enriched Organic
Combined Chemical and Organic
Chemical
Control

*Time effect significant at 0.01 level and treatment effect at 0.05 level.

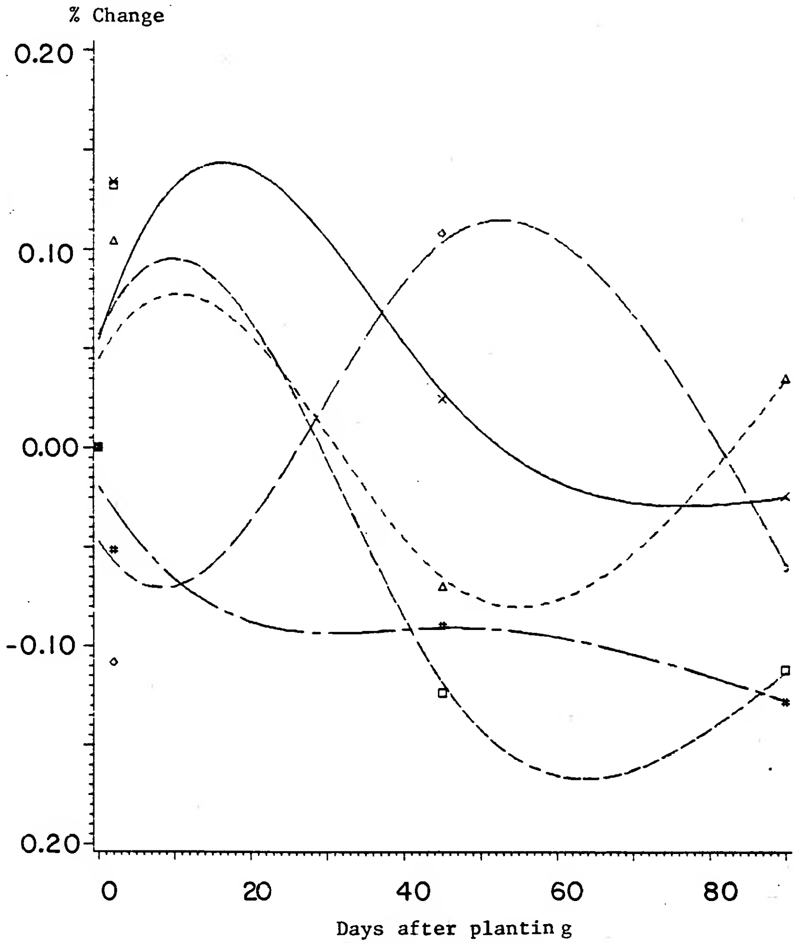


Fig. 32. Change in iron content of soil, Cariari.*

Fertilizer Treatment

Unenriched Organic
Combined Chemical and Organic
Control
Enriched Organic
Chemical

*Treatment e-fect significant at 0.05 level.

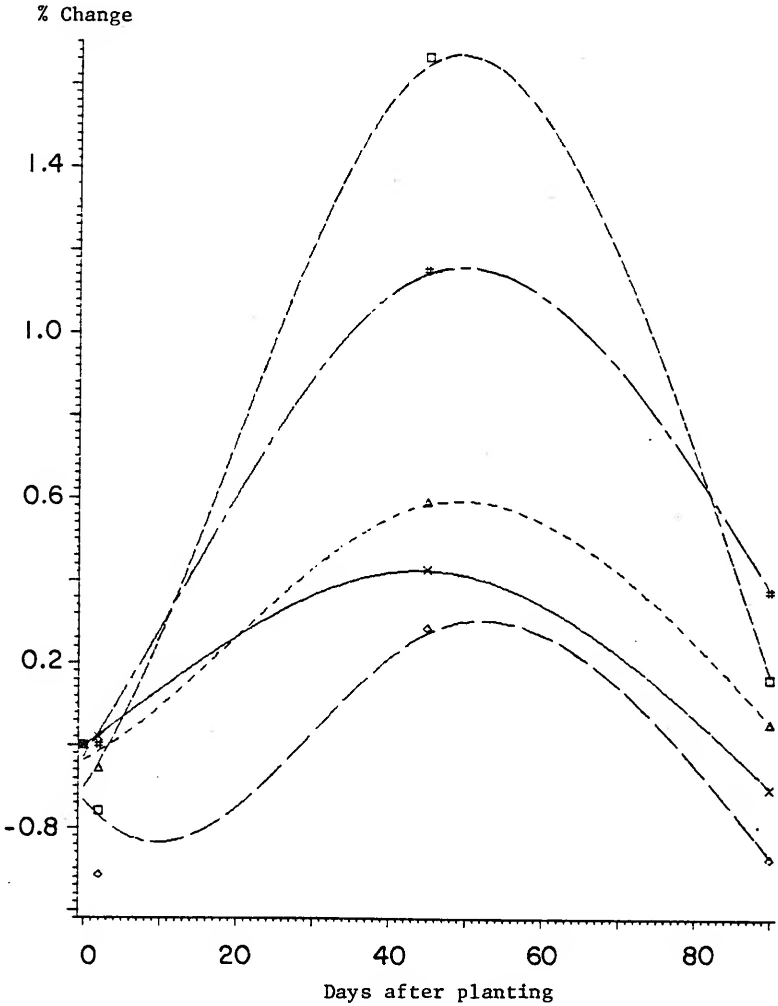


Fig. 33. Change in iron content of soil, La Pacífica.*

Fertilizer Treatment

Unenriched Organic
Enriched Organic
Combined Chemical and Organic
Chemical
Control

*Time effect significant at 0.01 level.

Table 40. Analysis of variance, organic matter content of soil, CATIE.

Source	df	Mean Square	F Value
Time	3	1.66	5.29**
Treatment	4	0.74	2.37
Block	3	0.25	0.79
Time X Treatment	12	0.72	2.29
Error	137	0.31	

Table 41. Analysis of variance, organic matter content of soil, Cariari.

Source	df	Mean Square	F Value
Time	3	9.32	5.50**
Treatment	4	6.32	3.73**
Time X Treatment	12	1.85	1.09
Farm	2	36.72	21.65**
Time X Farm	6	3.90	2.30*
Treatment X Farm	8	22.21	8.67**
Time X Trmt X Farm	24	2.46	1.45
Error	178	1.70	

Table 42. Analysis of variance, organic matter content of soil, La Pacífica.

Source	df	Mean Square	F Value
Time	3	1.60	1.50
Treatment	4	2.27	2.14
Block	4	8.83	8.31**
Time X Treatment	12	0.91	0.85
Error	173	1.06	

the organically treated plots did show a significantly higher overall organic matter content, but overall organic matter content was no higher at 90 days than originally. Further, absolute increase in organic matter over the period of sampling was actually higher on chemically treated plots at Cariari (Fig. 34) and at La Pacífica (Fig. 35); final organic matter content of all organically treated plots was depressed compared to initial values. At Turrialba (Fig. 36), the plots treated with unenriched compost and the plots treated with mixed chemical and organic fertilizer did show an increase in organic matter content over time, but chemically fertilized plots did so as well, while those receiving enriched compost did not.

These data show that the residence time of the organic matter in the soil was, in most cases, very short, and that even large applications of organic matter did not significantly alter the organic matter of the soil for more than a short period of time. The problem with the data is that they represent a very short time frame. Very different results might be obtained if compost were applied repeatedly, over longer periods of time. Swift and Posner (1972) note, for example, that changes in soil organic matter content and characteristics are very complex and rapid in the first three months after initial application, and proceed more slowly thereafter. Similarly, Paul and McGill (1974) found that residence time of labelled carbon differed greatly with soil type. Further, most of these soils have been fertilized chemically in the past. There is probably an interaction between prior and current fertilization practice that is completely unclear. A much longer period of

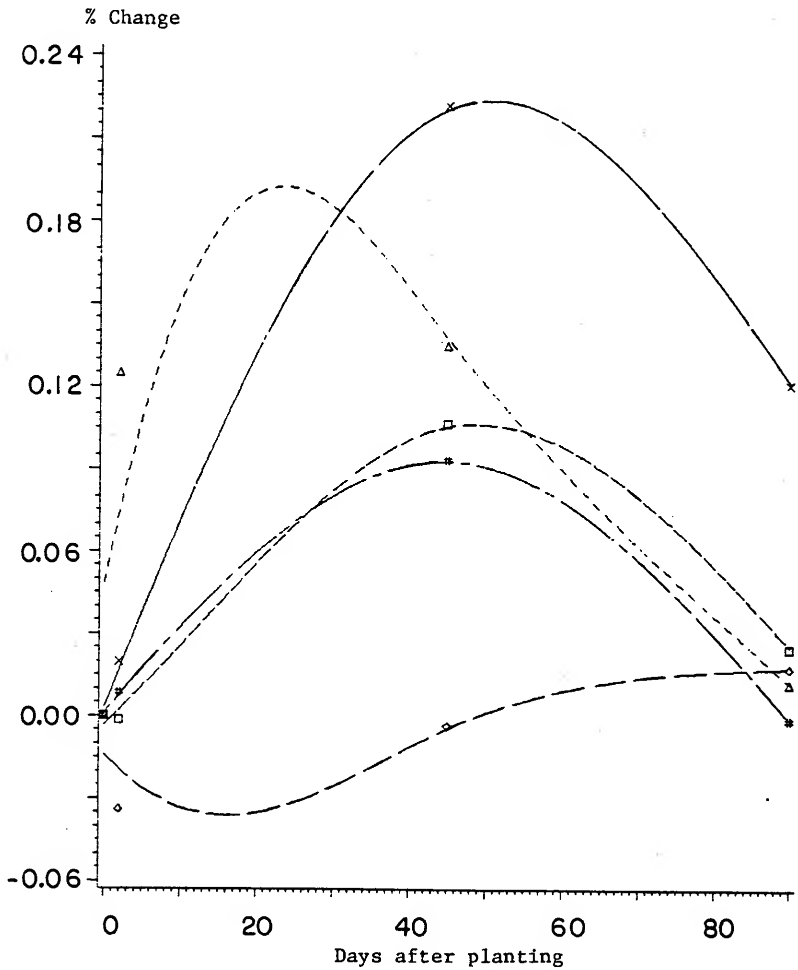


Fig. 34. Change in organic matter content of soil, Cariari.*

Fertilizer Treatment

Unenriched Organic
Enriched Organic
Combined Chemical and Organic
Chemical
Control

*Time and treatment effects significant at 0.01 level.

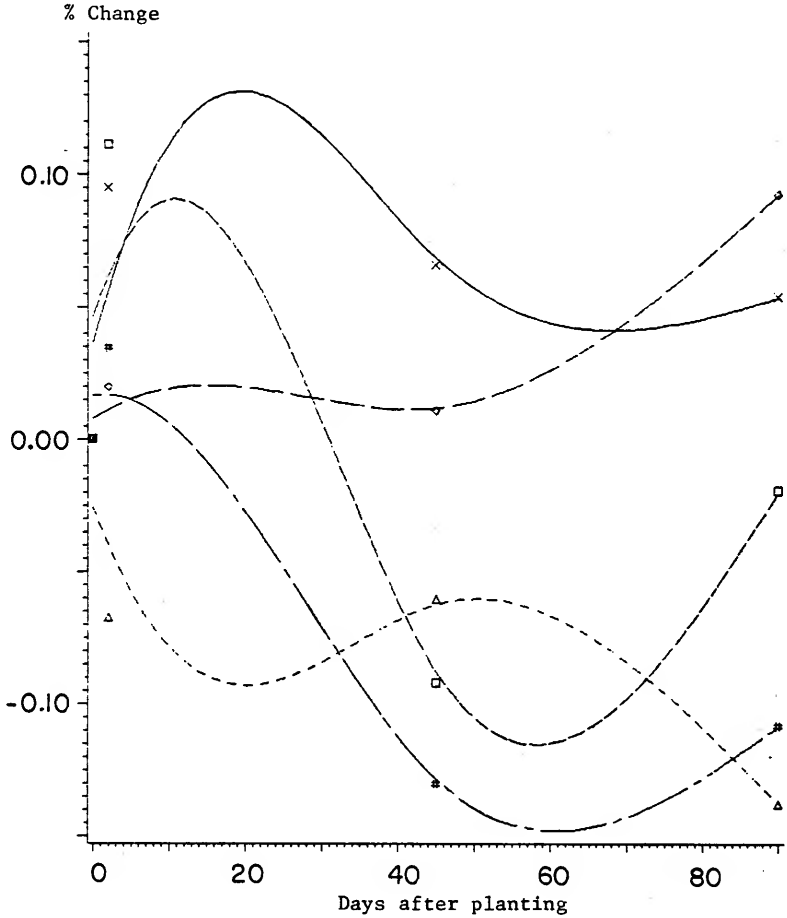


Fig. 35. Change in organic matter content of soil, La Pacífica.*

Fertilizer Treatment

Unenriched Organic
Combined Chemical and Organic
Control
Enriched Organic
Chemical

*Time and treatment effects significant at 0.01 level.

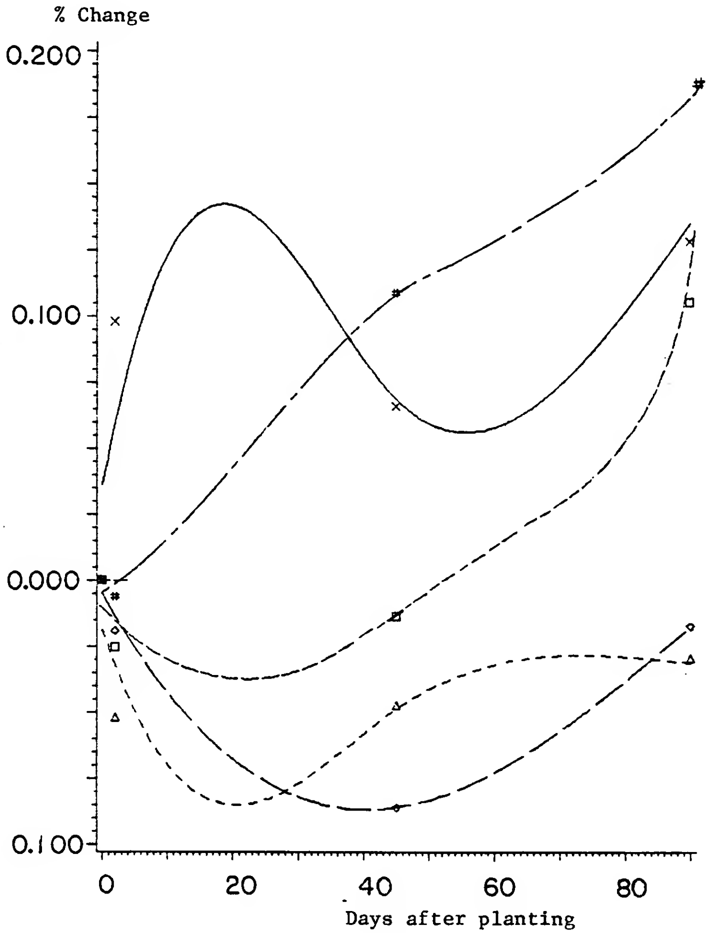


Fig. 36. Change in organic matter content of soil, CATIE.*

Fertilizer Treatment

Unenriched Organic
Combined Chemical and Organic
Control
Enriched Organic
Chemical

*Time effect significant at 0.01 level and treatment effect at 0.05 level.

investigation is required to understand these phenomena. It is, however, clear that addition of organic matter does not necessarily, under these conditions, increase soil organic matter content as is so often assumed.

Labor Demand

Table 43 shows the labor demand for producing compost. As the table shows, collecting and chopping the vegetative material are by far the most labor-consuming tasks. Collecting sorghum stover was particularly time-consuming, and chopping stover made a high labor demand at Cariari where no mechanical chopper was available. Since the milking parlor must be cleaned, this labor cost should not really be included here.

Using an average of all values, the labor cost of producing 100 kg of compost is 5.95 hours. If this labor were salaried, this would be a labor cost of $US 5.23 per 100 kg compost. Again, using average values for all sites, 100 kg of compost would contain an average of 1.27 kg nitrogen, 1.00 kg phosphate, and 3.85 kg potash. The average cost of production of one kg of plant nutrients (N, P_2O_5, K_2O) is $US 0.94. In April, 1981, one kg of the same plant nutrients in a commercial fertilizer mix (15-15-15) was valued at $0.81. The cost of the two is, then approximately the same.

The application of the compost, however, requires approximately twice as long as the application of chemical fertilizer. The application time would be reduced if the compost were not incorporated into the soil, but incorporation is probably critical for effective use.

Table 43. Labor demand of composting.

Task	Hours/100 kg Material	Site
Collect Stover	5	Cariari
	5	Turrialba
	9	La Pacífica
Chop Stover	10	Cariari
	1	Turrialba
	1	La Pacífica
Construct Compost Heaps	0.2	Cariari
	0.5	Turrialba
	0.5	La Pacífica
Maintain Compost Heaps	0.4	Cariari
	0.2	Turrialba
	0.4	La Pacífica
Collect Manure	0.5	All Sites

This labor demand could be reduced considerably where farmers have the land plowed, as many do in Cariari, for example, since the compost could be broadcast and then incorporated by plowing. The labor involved in application on the test plots was probably excessive because the compost was applied in trenches. Nonetheless, even under the best circumstances, applying compost will be more demanding than using chemical fertilizer.

The practicality of compost use, from this point of view, will depend on many factors. First, most farm labor is not paid labor. Therefore, if family labor is available, the actual cost of producing the material would be very low.

Second, producing compost generally will not conflict with other labor demands since the materials can be collected and the heaps constructed after harvest, or at virtually any time in the year. Where crops must be planted in a very short time, however, such as at the La Pacífica site, the high labor demand at planting would be a constraint on the use of compost. In Cariari, on the other hand, where the planting season is much longer, this constraint is much less limiting.

Third, the labor demand will vary in importance depending on the crop being grown. Corn is a low value crop, which many farmers do not even fertilizer. Vegetables, on the other hand, are a high value crop. Further, bed preparation for vegetables is a labor-consuming process itself and the added labor from applying compost is much less likely to be viewed as a constraint.

Finally, the relative importance of these factors will change with the cost of labor and fertilizer prices in the country. Today, fertilizer costs are rising rapidly. As the cost of fertilizer rises, the practicability of using this technology will increase. On the other hand, labor costs are also increasing, although not as rapidly, and family labor on the farm is often a scarcity in Costa Rica. These factors will change over time, and their effect cannot be predicted.

In the three zones where interviews were conducted, the majority of the farmers interviewed could produce compost. In Cariari, 62% of the farms (n = 21) had enough cattle to make compost production feasible (at least 5 head of cattle). However, most of these farmers fo not now produce milk. If they do milk animals, it is only once a day and usually not under cover. The possibilities for collecting manure are therefore limited, although some farmers did indicate that sizeable quantities of manure do accumulate in open corrals. Manure that accumulates in this fashion is, of course, highly susceptible to nutrient loss from leaching. Manure samples were collected from 13 farms and showed an average nitrogen content of 1.60% (dry weight basis). If dairying gains importance in the colony, manure collection would be facilitated.

Supplies of vegetative material are not a problem. Banana leaves and waste are one possibility. They are much less labor intensive to collect than other wastes and do make a good compost. Corn stover and bean trash are also available. Chopping vegetative material, which has a very high labor demand if done by hand, is a problem. Only one farmer interviewed owned a mechanical chopper.

Of the farmers interviewed, 67% indicated that they do use some fertilizer. While all had some type of pasture, none fertilized it. Annual crops, pirncipally corn and beans, were planted on 95% of the farms, and 55% of the annual crops received some fertilizer. Nearly half, 48%, of the farmers also had some perennial crops, and 40% of those farmers did fertilizer their perennials. Vegetable production is very limited in Cariari. Only one farmer interviewed grew vegetables. Only three fertilizer mixes are used with any frequency in Cariari, 12-24-12, 10-30-10, and urea. The toal amount of fertilizer used is also very limited. While farmers' responses as to use varied greatly, a typical farm from the interview group might use a total of 250 to 300 kg of fertilizer per year.

The best possibilities for utilizing compost in this zone are probably on perennial crops, especially pejibaye and cacao. Corn is sometimes fertilized as well, and compost could be used on corn. Corn is, on the one hand, a relatively low value crop. On the other hand, the current practice is to supply very small amounts of fertilizer. Given the quantities used, compost probably could replace or greatly supplement current use.

Only two of the farmers interviewed reported that they use the manure available to them in any way, both on cacao. By far the most frequently cited reason (38%) for not doing so is the difficulty in collecting it. The farmers were not referring in this case to the problems with storage or labor, but rather to the fact that the combination of open corrals and high rainfall makes collection difficult. It would need to be done virtually daily. The high labor demand was

cited by 19% as the reason for not using manure, and another 19% stated that they lacked information about how to properly use the manure. The small quantity available was mentioned by two farmers, as well.

Only five of the original ten farmers who were interviewed by CATIE in 1977-78 (CATIE, 1978) could be located. Of those five, only one now has no dairy cows. In general, dairies are very common in Turrialba. Most farmers milk only once a day, but corrals do tend to be roofed and collecting enough manure for composting is not a problem for most farms with cattle. During some parts of the year, during cane harvest, large amounts of vegetative material that can easily be collected are also available. Both bagasse and cane leaves can be used. During the remainder of the year there are sources of material, such as weeds, stover, and so on, but the labor demand for collection is higher for these materials.

As in Cariari, fertilizer use on pasture is limited. Only one farmer stated that he fertilized his pasture. Annual crops are much less important. Only three farmers grow corn and beans in Turrialba, and fertilizer use on annual crops is very limited. Perennial crops, however, especially coffee and cane, are very important around the area. All collaborators interviewed by the author raise these two crops, and all of them fertilize them. While commercial vegetable production is important in the zone, only one of these farmers grew vegetables.

The best possibility for the use of compost in this area is probably on perennial crops, especially coffee. Coffee is a high

value crop. Further, the fertilizer could be applied once a year, which would reduce labor in its application. Use on cane is a possibility as well. The area devoted to a crop such as coffee on these farms is very small, so that using compost should be feasible. Two of the five farmers interviewed do make compost and use it. Those who do not feared the spread of disease, or felt they did not have enough manure to collect.

Of the fourteen farmers interviewed at Santa Elena, 86% could collect manure. In the upper zone in particular several cows are milked twice a day. Manure collection is, therefore, not a problem. Average nitrogen content in the samples collected from these farms was 1.65%. Sources of vegetative material include waste from chopped tall grass pasture, easily collected, and weeds and other more labor demanding sources. Of the farmers interviewed, 70% had mechanical choppers, and all in the upper zone had them.

About 65% of the interviewees fertilize. Almost all in the upper zone fertilize pasture, and vegetables were grown by 30% of all those interviewed and fertilizer was used by 75% of those farmers. Annual and perennial crops are rarely fertilized (18% of all annual crops and 25% of the perennial crops). Farms where vegetables are grown commercially and that also produce milk have excellent possibilities for use of compost. On other farms, the compost could be used on tall grass pasture, where it could easily be applied.

Manure is used by some farmers, about 30% of those interviewed, although two of those did so as a result of working with the author. The major problem in its use was simply a lack of an efficient system

for collecting and using it. Labor demand was also cited frequently. Two farmers cited fear of the spread of disease and weeds as a major constraint.

CHAPTER VI
CONCLUSIONS

The data presented here indicate that it is possible to produce a stable organic fertilizer rapidly under field conditions and using a very simple technology under the range of environmental conditions that were explored. The technique that was used could be improved considerably in some regards. This is especially the case with regard to very high precipitation sites such as Cariari.

First, the initial C:N ratio could be considerably higher than those reported here, even where easily degradable materials are used. Since the product stabilized very rapidly, the usual problem of high initial C:N ratios delaying stabilization of the material is not a constraint. Even where fertilizer is needed frequently, the farmer should be able to produce sufficient amounts of compost to meet his needs. Raising the initial C:N ratio could help eliminate the early nitrogen loss experienced in most trials. On the other hand, collecting vegetative material creates by far the highest labor demand involved in compost production, especially on dairy farms, where manure collection creates very little additional labor demand. Therefore, the nitrogen loss that results from low initial C:N ratios must be weighed against the high labor cost that raising the C:N ratio entails.

More important, a better method of aeration is needed and, in high rainfall sites, a better way to protect compost heaps from precipitation. Nitrogen loss was very high, regardless of the treatment

or initial C:N ratio at the high rainfall sites. Insertion of a horizontal layer of bamboo chimneys could alleviate this problem. A more effective method of covering the heaps may be needed as well.

Extremely high concentrations of certain elements, potassium, aluminum, iron, manganese, and zinc, were found at the first CATIE trials. These very high concentration rates were probably due to the addition of soil to the heaps. No significant differences were found between enriched and unenriched treatments, except at that first CATIE trial, for these elements. Since it is not necessarily desirable to apply these elements in large quantities, the practice of applying a layer of soil to the compost heap probably should not be followed, at least where the soil is high in these elements.

Calcium, magnesium, and nitrogen were all lost, probably due to leaching, at the very humid sites. While this poses no problems in the use of the compost later in the case of calcium and magnesium, the nitrogen level of the final product at Cariari was very low. The overall low nitrogen content probably contributed to the depression of soil nitrogen levels observed on the test plots where compost was applied, and may have contributed to the somewhat lower corn yields that those plots produced.

Although the temperatures in the compost heaps did not reach the very high values that some authors have reported, the temperature was probably adequate to kill disease bearing organisms. Further, the process was concluded rapidly, indicating that adequate temperatures were obtained. While pH did not follow the same patterns reported by other authors, pH values remained well within acceptable

limits at all times. A greater amount of phosphate could probably be added to enriched heaps given that the addition of the phosphate did not greatly affect the pH of the heaps.

In all three zones where interviews were conducted a large number of farmers indicated that they could produce compost. Manure availability and collection is a constraint only in Cariari, where dairying is not very important today. Collection of vegetative material for use in the heaps, on the other hand, is a problem. In almost every case, some kind of material is available, but much of it is very difficult to use because of the high labor demand involved in its collection. One avenue of research that should be pursued is to find better sources of such material. Coffee pulp might be one such source, for example. This problem is exaccerbated in areas where few farmers have mechanical choppers.

The crops to which the compost could be applied vary from zone to zone. Use on perennial crops, in areas where they are important, appears to be one excellent possibility. In Turrialba to some extent, and in Santa Elena, application on vegetable crops is suggested. While it is possible to apply compost to crops such as corn, the low market value of these crops may make the practice uneconomical. On the other hand, the very small amounts of fertilizer that are applied to these crops means that very little compost would have to be produced to meet this demand, or to supplement current fertilizer useage.

Yield responses of corn to the application of compost, even though only one application was made, were comparable to responses on chemically fertilized. Some reduction in yield was noted, as

compared to chemically treated plots, but this could probably be corrected by producing a better compost at very humid sites, such as Cariari, and by applying larger quantities of compost so that the effective nitrogen application rate is raised. A major problem is that the compost is deficient in phosphate. Since it is difficult for farmers in Costa Rica to buy phosphatic fertilizer, the use of a mix of chemical and organic fertilizer may be the best option. This treatment also resulted in yields comparable to those obtained using chemical fertilizer. Another alternative would be to increase the amount of phosphate added to the compost. It should be noted, however, that mixed chemical and organic fertilizer did not illustrate the same capacity to maintain soil pH at high values as did organic fertilizer alone.

The cost of producing compost, if cost of labor is included, is about the same as that of purchasing chemical fertilizer, as of April 1, 1981. As the cost of chemical fertilizers continues to increase, the production of compoast may become more competitive. Labor, however, is in short supply on many farms in Costa Rica and the labor demand not only of making compost, but especially that involved in its application, may make its use impractical on many farms. This problem is exaccerbated where a crop must be planted within a very short period of time, such as in Guanacaste where planting is carefully times to coincide with the onset of the rainy season. Where the land is plowed, compost could be broadcast and then incorporated by plowing, and in some areas, such as Cariari, many farmers do pay to have their land plowed. Again, use with

perennials or vegetable crops could also alleviate this constraint.

While some interesting data were obtained regarding the effect of different fertilizer treatment on soil chemical properties, these data can only be regarded as preliminary. First, the effects of adding large amounts of organic matter to the soil, both positive and negative, will be illustrated completely only after the practice has been continued for many years. Second, there are probably some effects that are a result of the change from chemical to organic fertilization. In order to better understand how the use of an organic material such as compost would affect soil properties a much longer period of study would be required.

LITERATURE CITED

Abd-El-Malek, Y., M. Monib, S. G. Righ, and S. M. Shehata. 1976. Biological activities during ripening of compost. Abl. Bakt. Abt., Bd. 131:744-750.

Adriano, D. C., P. F. Pratt, and S. E. Bishop. 1971. Fate of inorganic forms of N. and salt from land-disposed manures from dairies. p. 243-246. In Livestock waste management and pollution abatement. Proc. Int. Conf. on Livestock Wastes. Am. Soc. Agric. Eng., St. Joseph, Mich.

Agboola, A. A., G. O. Obigbesan, and A. A. A. Fayeme. 1975. Interrelation between organic and mineral fertilizers in the tropical rain forests of western Nigeria. p. 337-352. In Organic materials as fertilizers. Soils Bull. no. 27, Food and Agricultural Organization, Rome.

Allen, M. B. 1949/50. The dynamic nature of thermophily. J. Gen. Physiol. 33:205-214.

Anderson, J. R. 1967. Biological interrelationships between feces and flies. p. 20-23. In Proc. Natl. Symp. on Animal Waste Management. Am. Soc. Agric. Eng., East Lansing, Mich.

Anjos, N. M. dos, and J. F. Noronha. 1974. Analise dos mercados internacional e Brasileiro de fertilizantes. Agric. Sao Paulo 20:1-23.

Aslander, A. 1950. The availability of phosphates after standard fertilization. Int. Cong. Soil Sci. Trans. 4th 2:158-163.

Aste, V. A. 1971. Estudio de suelos del area del Centro Agronómico Tropical de Investigación y Enseñanza, IICA-Turrialba, Costa Rica. M. S. Thesis. Instituto Interamericano de Ciencias Agrícolas de la Organización de Estados Americanos, Turrialba.

Atchley, S. H., and J. B. Clark. 1979. Variability of temperature, pH, and moisture in an aerobic composting process. Appl. Environ. Microbiol. 38:1045-1051.

Avila, M. 1979. Unedited summaries of farm management information on 40 farms in 4 regions of Costa Rica, April 1978-March 1979, CATIE/IRDC Project. Centro Agronómico Tropical de Investigación y Enseñanza, Turrialba.

Bache, B. W., and R. B. Heathcote. 1969. Long term effects of fertilizers and manure on soil and leaves of cotton in Nigeria. Exptl. Agric. 5:241-247.

Bagstam, G. 1978. Population changes in microorganisms during composting of spruce-bark. I. Influence of temperature control. Europe. J. Microbiol. Biotechnol. 5:315-330.

Bagstam, F. 1979. Population changes in microorganisms during composting of spruce bark. II. Mesophilic and thermophilic microorganisms during controlled composting. European J. Appl. Microbiol. Biotechnol. 6:279-228.

Beaver, P. C., and G. Deschamps. 1949. The viability of E. histolytica cysts in soil. Amer. J. Trop. Med. 29:189-191.

Bell, R. G., D. G. Wilson, and E. J. Dew. 1976. Feedlot manure top dressing for irrigated pasture: Good agricultural practice or a health hazard. Bull. Environ. Contam. Tox. 16:536-540.

Borgstrom, G. 1965. The hungry planet. Collier-Macmillan, London.

Bremmer, J. M. 1965. Total nitrogen. p. 1149-1177. In C. A. Black, D. D. Evans, J. L. White, L. F. Esminger, F. F. Clark, and R. C. Cinauer (eds.) Methods of soil analysis. Part 2. Chemical and microbiological properties. Am. Soc. Agron., Madison.

Bruin, P. 1969. Still on about chemical versus organic farming. Stikstof 13:16-28.

Burnett, C. A. 1975. The agricultural use of organic material in Brazil. p. 305-311. In Organic materials as fertilizers. Soils Bull. no. 27, Food and Agricultural Organization, Rome.

Carlyle, R. E., and A. G. Norman. 1941. Microbial thermogenesis in the decomposition of plant materials. Part II. Factors involved. J. Bacteriol. 41:699-724.

Centro Agronómico Tropical de Investigación y Enseñanza. 1978. Project milk and beef production systems for small farmers using crop derivaties, 1977 progress report, revised version. Centro Agronómico Tropical de Investigación y Enseñanza, Turrialba.

Centro Agronómico Tropical de Investigación y Ensenanza. 1980a. Projecto de investigación aplicada de producción de leche para campesinos de recursos limitados, primer informe annual. Centro Agronómico Tropical de Investigación y Enseñanza, Turrialba.

Centro Agronómico Tropical de Investigación y Enseñanza. 1980b. Projecto de investigación aplicada de producción de leche para campesinos de recursos limitados, proyecto CATIE/BID, enquestas. Centro Agronómico Tropical de Investigación y Enseñanza, Turrialba.

Chakravorti, S. P. 1979. Effects of application of urea and ammonium sulfate blended with neem cake and compost on N transformation in soil and yield and nutrition of rice. J. Indian Soil Sci. Soc. 27:449-451.

Chambers, R., and B. H. Farmer. 1977. Perceptions, technology, and the future. p. 313-350. In B. H. Farmer (ed.) Green revolution. Westview Press, Boulder.

Chubin, R. G. 1981. Plant availability, absorption, mobility and extractability of cadmium in selected Florida soils amended with sewage sludge. M. S. Thesis. University of Florida, Gainesville.

Clapp, C. E., D. R. Duncomb, W. E. Larson, D. R. Linden, R. H. Dowdy, and R. E. Larson. 1978. Crop yields and water quality after application of sewage sludge to an agricultural watershed. p. 185-198. In R. C. Loehr (ed.) Food, fertilizer and agricultural residues. Proc. 1977 Cornell Agric. Waste Management Conf. Ann Arbor Science Publishers, Ann Arbor.

Cleave, J. H., and E. H. Jones. 1970. The economic background. p. 109-126. In T. D. Jameson (ed.) Agriculture in Uganda, 2nd ed. Oxford University Press, London.

Cole, H. S. D., C. Freeman, M. Jakoda, and K. L. R. Ravitt (eds.). 1973. Models of doom. Universe Books, New York.

Concannon, T. J., and E. J. Genetelli. 1971. Groundwater pollution due to high organic manure loadings. p. 249-253. In Livestock waste management and pollution abatement. Proc. Int. symp. on Livestock. Am. Soc. Agric. Eng., St. Joseph, Michigan.

Cooke, R. C. 1977. Fungi, man and his environment. Longman, London.

Cooney, D. G., and R. Emerson. 1964. Thermophilic fungi. W. H. Freeman and Co., San Francisco.

Copeland, R. J., and C. E. Merkle. 1941. The influence of certain soil treatments upon the fixation and availability of applied phosphates. Soil Sci. Soc. Amer., Proc. 6:321-326.

Dahlberg, K. A. 1979. Beyond the green revolution. Plenum Press, New York.

Dalton, J. D., G. C. Russell, and D. H. Sieling. 1952. Effect of organic matter on phosphate availability. Soil Sci. 73:173-181.

Davis, C. H., and G. M. Blouin. 1977. Energy consumption in the U.S. chemical fertilizer system from the ground to the ground. p. 315-331. In W. Lockeretz (ed.) Agriculture and energy. Academic Press, New York.

Decker, W. M., and J. H. Steele. 1967. Health aspects and vector control associated with animal wastes. p. 18-20. In Proc. Natl. Symp. on Waste Management. Am. Soc. Agric. Eng., East Lansing, Michigan.

Demmel, D. 1980. Farm-scale composting: An option to anaerobic digestion. Compost Sci. Land Util. Jan./Feb.:3-5.

Department of Environmental Health, Institute of Health, Chinese Academy of Medical Sciences. 1977. Sanitary effects of urban garbage and night soil composting in China. Compost. Sci. 18:22-24.

Diaz-Romeu. 1978. Características químicas de suelos de sitios experimentales del proyecto de sistemas de producción para pequeños agricultores en Guácimo y Cariari, Provincia de Limon, Costa Rica. Centro Agronómico Tropical de Investigación y Enseñanza, Turrialba.

Djokoto, R. K., and D. Stephens. 1961a. Thirty long-term fertilizer experiments under continuous cropping in Ghana. I. Crop yield and response to fertilizers and manuers. Emp. J. Exptl. Agric. 29:181-195.

Djokoto, R. K., and D. Stephens. 1961b. Thirty long-term fertilizer experiments in Ghana. II. Soil studies in relation to the effects of fertilizers and manures on crop yield. Emp. J. Exptl. Agric. 29:245-258.

Duncan, A. 1975. Economic aspects of the use of organic materials as fertilizers. p. 353-378. In Organic materials as fertilizers. Soil Bull. no. 27, Food and Agricultural Organization, Rome.

Duthie, D. W. 1937. Studies in tropical soils. IV. Organic transformations in soils, composts and peat. J. Agric. Sci. 27:162-177.

Egawa, T. 1975. The use of organic fertilizers in Japan. p. 253-272. In Organic materials as fertilizers. Soils Bull. no. 27, Food and Agricultural Organization, Rome.

Ehrlich, P. R. 1968. The population bomb. Ballantine Books, New York.

Elliott, L. F., G. E. Schuman, and F. G. Veits, Jr. 1971. Volitalization of nitrogen containing compounds from beef cattle feedlot area. Soil Sci. Soc. Amer., Proc. 35:752-755.

Faust, E. C. 1924. Some facts regarding the relation between night-soil disposal in China and the propagation of helminthic diseases. Am. J. Trop. Med. 4:487-503.

Faust, E. D., P. C. Beaver, and R. C. Jung. 1975. Animal agents and vectors of human disease. Lea and Febiger, Philadelphia.

Fertilizantes de Centroamerica, S.A. 1981a. Consumo nacional de fertilizantes y area fertilizada (por cultivo). Mimiographed sheet. Fertilizantes de Centroamerica, S.A., San Jose.

Fertilizantes de Centroamerica, S.A. 1981b. Precio de venta de fertilizantes de Centroamerica, S.A., San Jose.

Finstein, M. S. 1980. Composting microbial ecosystem: Implications for process design and control. Compost Sci. Land Util. July/Aug.:25-27.

Food and Agricultural Organization. 1975. Organic materials as fertilizers. Soils Bull. no. 27. Food and Agricultural Organization, Rome.

Food and Agricultural Organization. 1976. Development of a programme promoting the use of organic materials as fertilizers. Food and Agricultural Organization, Rome.

Food and Agricultural Organization. 1977. China: Recycling of organic wastes in agriculture. Food and Agricultural Organization, Rome.

Food and Agricultural Organization. 1978a. Organic material and soil productivity. Soils Bull. 35. Food and Agricultural Organization, Rome.

Food and Agricultural Organization. 1978b. The state of food and agriculture. Food and Agricultural Organization, Rome.

Fukuoka, M. 1978. The one-straw revolution. Rodale Press, Emmaus, Penn.

Galler, W.S., and C. B. Davey. 1971. High rate poultry manure composting with sawdust. p. 159-163. In Livestock waste management and pollution abatement. Proc. Int. Symp. on Livestock Wastes. Am. Soc. Agric. Eng., St. Joseph, Mich.

Gammon, N. 1976. Soil microelements. Mimeographed sheet. University of Florida, Gainesville.

Garner, H. V. 1966. Comparisons of farmyard manure, sewage sludge, and other organic manures tested on potato and a succeeding crop at Rothamsted. J. Agric. Sci., Camb. 67:267-280.

Gaskill, J. O., and J. C. Gilman. 1939. Role of nitrogen in fungus thermogenesis. Plant Physiol. 14:31-53.

Golueke, C. G. 1972. Composting: A study of the process and its principles. Rodale Press, Emmaus, Penn.

Golueke, C. G. 1974. Biological reactions in solid waste recovery systems. Compost Sci. 15:2-6.

Golueke, C. G., B. J. Card, and R. H. McGaukley. 1954. A critical evaluation of innoculums in composting. Appl. Microbiol. 2:45-53.

Gotaas, H. B. 1956. Composting: Sanitary disposal and reclamation or organic wastes. World Health Organization, Geneva.

Greenland, D. J. No date. Biological and organic aspects of plant nutrition. Unpublished. Department of Soil Science of the University of Reading, Reading, England.

Greenstreet, V. R. 1928. Artificial farmyard manure. Malay Agric. J. 16:194-203.

Grimes, R. C., and R. T. Clarke. 1962. Continuous arable cropping with the use of manure and fertilizer. E. Afr. Agric. For. J. 28:74-80.

Grossman, E. D., and J. R. Thygeson. 1974. Farm and field wastes. p. 147-174. In T. F. Yen (ed.) Recycling and disposal of solid wastes. Ann Arbor Science Publishers, Inc., Ann Arbor.

Guinard, A. 1967. Conservation and improvement of soil fertility in Africa. Part 2. Organic manure. World Crops 19:29-31.

Hagenhauer, B. 1981. Unpublished weather data for Finca La Pacífica, Cañas, Costa Rica. Finca La Pacífica, Cañas.

Harriss, B. 1977. Marketing scarce chemical inputs: An international comparison. p. 256-267. In B. H. Farmer (ed.) Green revolution. Macmillan, London.

Hartley, K. T. 1937. An explanation of the effect of farmyard manure in northern Nigeria. Emp. J. Exptl. Agric. 5:254-263.

Heck, A. F. 1931. Conservation and availability of the nitrogen in farm manure. Soil Sci. 31:335-358.

Hemingway, R. G. 1961. The mineral composition of farmyard manure. Emp. J. Exptl. Agric. 29:14-18.

Hegg, R. O., and H. D. Skipper. 1977. Effects of poultry waste effluent and insecticides on corn production. p. 509-520. In R. C. Loehr (ed.) Food, fertilizer and agricultural residues. Ann Arbor Science Publishers, Inc., Ann Arbor.

Hesse, P. R. 1971. A textbook of soil chemical analysis. Chemical Publishing Co., New York.

Hileman, L. H. 1971. Effect of rate of poultry manure application on selected soil chemical properties. p. 247-248. In Livestock waste management and pollution abatement. Proc. Int. Symp. on Livestock Wastes. Am. Soc. Agric. Eng., St. Joseph, Mich.

Hojovec, J. 1977. Health effects from waste utilization. p. 105-109. In. E. P. Taiganides (ed.) Animal wastes. Applied Science Publishers, Ltd., London.

Hopper, D. 1976. The development of agriculture in the developing countries. Sci. Am. 235:196-205.

Instituto Meterológico Nacional. 1979a. Weather records for Los Diamantes, Guápiles, Costa Rica. Instituto Meterológico Nacional, San José.

Instituto Meterologico Nacional. 1979b. Weather records for La Taboga, Cañas, Costa Rica. Instituto Meterológico Nacional, San José.

Instituto Meterológico Nacional. 1979c. Weather records for Turrialba, Costa Rica. Instituto Meterológico Nacional, San José.

Jain, M. K., K. A. Kapoor, and N. N. Mishra. 1979. Cellulase activity, degradation of cellulose and lignin, and humus formation by thermophilic fungi. Br. Mycol. Soc., Trans 73:85-89.

James, L. H., L. F. Rettger, and C. Thom. 1941. Microbial thermogenesis. II. Heat production in moist organic materials with special reference to the part played by microorganisms. J. Bacteriol. 15:117-141.

Jameson, J. D., and R. K. Kerkham. 1960. The maintenance of soil fertility in Uganda. I. Soil fertility experiment at Jerere. Emp. J. Exptl. Agric. 28:179-192.

Jennings, P. R. 1976. The amplification of agricultural production. Sci. Am. 235:180-195.

King, F. H. 1911. Farmers of forty centuries. Democrat Printing Co., Madison.

Knuth, D. T. 1970. Nitrogen-cycle ecology of solid waste composting. Compost Sci. 11:8-12.

Krishnamurthy, R. 1966. A critical study of the investigations carried out on compost during the last sixty years with special reference to India. Indian J. Agron. 11:270-276.

Lambert, E. B. 1934. Distribution of oxygen and carbon dioxide in mushroom compost heaps as affecting microbial thermogenesis, acidity, and moisture therein. J. Agric. Res. 48:487-601.

Lane, C. 1934. The prevention of Ascaris infection: a critical review. Trop. Diseases Bull. 31:605-615.

Lauer, D. A. 1975. Limitations of animal waste replacement for inorganic fertilizers. p. 409-432. In Energy, agriculture and waste management. Proc. 1975 Cornell Agric. Waste Management Conf. Ann Arbor Science Publishers, Inc., New York.

Leach, G. 1976. Energy and food production. IPC Business Press Ltd., London.

Lenhard, G. 1963. Methods for the evaluation of composts. Compost Sci. 4:20-25.

Loehr, R. C. 1974. Agricultural waste management; problems, processes, and approaches. Academic Press, New York.

Lossin, R. D. 1970. Compost studies. Compost Sci. 11:16-17.

McCalla, T. M., L. R. Frederick, and G. L. Palmer. 1970. Manure decomposition and fate of breakdown products in soil. p. 241-255. In T. L. Willrich and G. E. Smith (eds.) Agricultural practices and water quality. Iowa State University Press, Ames.

McGarry, M. G., and J. Stainforth (eds). 1978. Compost, fertilizer and biogas production from human and farm wastes in the People's Republic of China. International Development Research Center, Ottawa.

Makhijani, A., and A. Poole. 1975. Energy and agriculture in the third world. Ballinger Publishing Co., Cambridge.

Mathers, A. C., and D. W. Goss. 1979. Estimating animal waste applications to supply crop nitrogen requirements. J. Soil Sci. Soc. Am. 43:364-366.

Mathur, B. S., A. K. Sarkar, and B. Mishra. 1980. Release of nitrogen and phosphorus from compost charged with rock-phosphate. J. Indian Soc. Soil Sci. 28:206-212.

Meadows, D. G., D. L. Meadows, J. Randers, and W. W. Behrens, III. 1972. The limits to growth. The New American Library, Inc., New York.

Meneses, R. 1979. Sistema de producción de maíz-maíz o maíz-frijol para la Zona Atlántica de Costa Rica. Centro Agronómico Tropical de Investigación y Enseñanza, Turrialba.

Menzies, J. D. 1976. Pathogen considerations for land application of human and animal wastes. p. 97-118. In L. B. Baldwin, J. M. Davidson, and J. F. Gerber (eds.) Soils for management of organic wastes and waste waters. University of Florida and United States Environmental Protection Agency, Gainesville.

Mesarovic, M., and E. Pestel. 1974. Mankind at the turning point. E. P. Dutton and Co, Inc., New York.

Metcalf, T. G. 1976. Prospects for virus infection in man and animals from domestic waste land disposal practices. p. 97-118. In L. B. Baldwin, J. M. Davidson, and J. F. Gerber (eds.) Virus aspects of applying waste to land. Institute of Food and Agricultural Sciences, University of Florida, Gainesville.

Ministerio de Agricultura, Consejo Agropecuário Nacional, Comisión de Fertilizantes. 1974. Informe sobre el consumo de fertilizantes en Costa Rica, preliminar. Ministerio de Agricultura, San José.

Ministerio de Agricultura, Dirección de Planeamiento, Departamiento de Economía y Estadísticas Agropecuárias. 1977. Precios promedio de algunos fertilizantes pagados por el consumidor en el mes do Julio de 1977, segun regiones agrícolas y por producto. Mimeographed sheet. Ministerio de Agricultural, San José.

Ministerio de Agricultura, Dirección de Planeamiento, Departamiento de Economía y Estadísticas Agropecuárias. 1978a. Precios promedio de algunos fertilizantes pagados por el consumidor en el mes de Enero de 1978, segun regiones agrícolas y por producto. Mimeographed sheet. Ministerio de Agricultura, San José.

Ministerio de Agricultura, Dirección de Planeamiento, Departamiento de Economía y Estadísticas Agropecuárias. 1978b. Precios promedio de algunos fertilizantes pagados por el consumidor en el mes de Julio de 1978, segun regiones agrícolas y por producto. Mimeographed sheet. Ministerio de Agricultura, San José.

Ministerio de Agricultura, Dirección de Planeamiento, Departamiento de Economía y Estadísticas Agropecuárias. 1979a. Precios promedio de algunos fertilizantes pagados por el consumidor en el mes de Enero de 1979, segun regiones agrícolas y por producto. Mimeographed sheet. Ministerio de Agricultura, San José.

Ministerio de Agricultura, Dirección de Planeamiento, Departamento de Economía y Estadísticas Agropecuárias. 1979b. Precios promedio de algunos fertilizantes pagados por el consumidor en el mes de Julio de 1979, segun regiones agrícolas y por producto. Mimeographed sheet. Ministerio de Agricultura, San José.

Ministerio de Agricultura, Dirección de Planeamiento, Departamento de Economía y Estadísticas Agropecuárias. 1980a. Precios promedio de algunos fertilizantes pagados por el consumidor en el mes de Enero de 1980, segun regiones agrícolas y por producto. Mimeographed sheet. Ministerio de agricultura, San José.

Ministerio de Agricultura, dirección de Planeamiento, Departamento de Economía y Estadisticas Agropecuárias. 1980b. Precios promedio de algunos fertilizantes pagados por el consumidor en el mes de Julio de 1980, segun regiones agrícolas y por producto. Mimeographed sheet. Ministerio de agricultura, San José.

Ministerio de Agricultura, Dirección de Planeamiento, Departamento de Economía y Estadísticas Agropecuárias. 1981a. Precios promidio de algunos fertilizantes pagados por el consumidor en el mes de Enero de 1981, segun regiones agrícolas y por producto. Mimeographed sheet. Ministerio de agricultura, San José.

Ministerio de Agricultura, Dirección de Planeamiento, Departamento de Economía y Estadísticas Agropecuárias. 1981b. Precios promedio de algunos fertilizantes pagados por el consumidor en el mes de Julio de 1981, segun regiones agrícolas y por producto. Mimeographed sheet. Ministerio de agricultura, San José.

Ministerio de Economía, Industria y Comercio, Dirección General de Estadísticas y Censos. 1974. Censos nacionales de 1973. Agropecuário, vol. 3. Ministerio de Economía, Industria y Comercio, San José.

Molen, H. 1974. A test case against fertilizers in Illinois (USA). Stikstof. 17:41-47.

Mudahar, M. S., and T. P. Hignett. 1981. Energy and fertilizer: policy illues and options for developing countries. Unpublished Discussion Paper. International Fertilizer Development Center, Muscle Shoals, Ala.

Murray, J. A. 1925. The science of soils and manures, 3rd ed. D. Van Nostrand Co., New York.

Nagar, B. R. 1975. Recommendations and guidelines. Proposals for short term research, long term research, extension, education and international cooperation. p. 379-387. In Organic materials as fertilizers. Soils Bull. no. 27. Food and Agricultural Organization, Rome.

National Academy of Sciences. 1977. Methane generation from human, animal, and agricultural wastes. National Academy of Sciences, Washington.

Nicolaides, J. 1980. Personal Communication. Raleigh, N. C.

Nnochiri, T. 1975. Medical microbiology in the tropics. Oxford University Press, London.

North Carolina Agricultural Extension Service. 1973a. Dairy waste management alternatives. North Carolina Agric. Ext. Service Circ. no. 568.

North Carolina Agricultural Extension Service. 1973b. Poultry waste management alternatives. North Carolina Agric. Ext. Service Circ. no. 570.

Obrist, W. 1966. Additives and the window composting of ground household refuse. Compost Sci. 6:27-29.

Odend'hal, S. 1972. Energetics of Indian cattle in their environment. Human Ecol. 1:3-22.

Organization of American States. 1970. The fertilizer situation in Costa Rica. Organization of American States, Washington.

Olsen, S. R., and L. A. Dean. 1965. Phosphorus. p. 1035-1049. In C. A. Black, D. D. Evans, J. L. White, L. F. Esminger, F. F. Clark, and R. C. Cinauer (eds.), Methods of soils analysis. Part 2. Chemical and microbiological properties. Am. Soc. of Agron., Madison.

Ortíz, C. 1981. Personal communication. San José, Costa Rica.

Parsons, D. J. 1970. Agricultural systems. p. 127-138. In J. D. Jameson (ed.) Agriculture in Uganda, 2nd ed. Oxford University Press, London.

Paul, E. A., and W. B. McGill. 1974. Turnover of microbial biomass, plant residues and soil humic constituents under field conditions. Can. J. Soil Sci. 54:149-157.

Pearson, R. W., and F. Adams. 1965. Soil acidity and liming. Am. Soc. Agron., Madison.

Peech, M. 1965. Hydrogen-ion activity. p. 914-926. In C. A. Black, D. D. Evans, J. L. White, L. F. Esminger, F. F. Clark, and R. C. Cinauer (eds.) Methods of soil analysis. Part 2. Chemical and microbiological properties. Am. Soc. Agron., Madison.

Perelman, M. 1976. The green revolution: American agriculture in the third world. p. 111-128. In R. Merrill (ed.) Radical agriculture. New York University Press, New York.

Perez-Garcia, M. 1948. Abono: Organicos o compostes. Departamiento de Agricultura y Comercio, San Juan, Puerto Rico.

Perrott, K. W. 1978. The influence of organic matter extracted from humidified clover on the properties of amorphous aluminosilicates. II. Phosphorus retention. Aust. J. Soil. Res. 16: 341-346.

Poincelot, R. P. 1974. A scientific examination of the principles and practices of composting. Compost Sci. 15:24-31.

Poleman, T. T. 1975. World food: A perspective. Science 188:510-518.

Polprasert, C., S. Wangsuphachart, and S. Muttamara. 1980. Composting nightsoil and water hyacinth in the tropics. Compost Sci. Land Util. March/April:25-27.

Price, D. R. 1981. Where farm energy goes. Part one of overview. p. 2-9. In Cutting energy costs, the 1980 yearbook of agriculture. United States Department of Agriculture, Washington.

Pritchett, W. L., and W. G. Blue. 1966. Fertilizer use in tropical America--Costa Rica, a case history. Soil Sci. Soc. Fla., Proc. 26:361-370.

Rastogi, R. C., B. Mishra, and B. P. Ghildyal. 1976. Effects of pryrite and organic matter on the release of phosphorus from rock phosphate. J. Indian Soc. Soil Sci. 24:175-181.

Regan, R. W., and J. S. Jeris. 1970. A review of the decomposition of cellulose and refuse. Compost Sci. 11:17-20.

Richardson, H. L. 1946. Soil-fertility maintenance under different systems of agriculture. Emp. J. Exptl. Agric. 53:1-17.

Richardson, J. L., and Y. Wang. 1942. Nitrogen conservation of night soil in Central China. I. Change in night soil, feces, and urine on storage. Soil Sci. 54:381-389.

Rodale, J. T. 1945. Pay dirt: Farming and gardening with composts. Rodale Press, Emmaus, Penn.

Rubins, E. J., and F. E. Bear. 1942. Carbon-nitrogen ratios in organic fertilizer materials in relation to the availability of their nitrogen. Soil Sci. 54:411-423.

Rybczynski, W. 1977. Appropriate sanitation for the world's poor. Compost Sci. 18:13-15.

Sadaphal, M. N., and T. Singh. 1979. The evaluation of superphosphate reinforced farm compost for wheat. Indian J. Agron. 24:81.

Salter, R. M., and C. J. Schollenberger. 1939. Farm manure. Ohio Agric. Exp. Stat. Bull. no. 605.

Satriana, M. J. 1974. Large scale composting. Noyes Data Corp., Park Ridge, N. J.

Schulze, K. L. 1962. Continous thermophilic composting. Appl. Microbiol. 10:108-122.

Schulze, K. L. 1960. Rate of oxygen consumption and respiratory quotients during the aerobic decomposition of a synthetic garbage. Compost Sci. 1:36-40.

Scott, J. C. 1952. Health and agriculture in China. Farber and Farber, London.

Shapley, D. 1977. Will fertilizers harm ozone as much as SST's Science 195:658.

Sherff, J. L. 1975. Energy use and economics in the manufacutre of fertilizers. p. 433-441. In W. J. Jewell (ed.) Energy, agriculture and waste management. Proc. 1975 Cornell Conf. on Agric. Waste Management. Ann Arbor Science Publishers, Inc., Ann Arbor.

Sigel, M. M., D. F. Rippe, S. D. King, E. Rose, F. Breakenridge, M. Dorsey, Jr., S. L. Watkins, Jr., L. Dunkley, and A. R. Beasley. 1976. Survival of enteric viruses under different environmental conditions. p. 53-58. In L. B. Baldwin, J. M. Davidson, and F. J. Gerber (eds.) Virus aspects of applying municipal waste to land. University of Florida, Gainesville.

Sikora, L. J., G. B. Willson, D. Colaccio, and J. F. Parr. 1981. Materials balance in aerated static pile composting. J. Water Poll. Control Fed. 53:1702-1707.

Sikora, L. J., G. B. Willson, and J. F. Parr. 1979. Adapting the Beltsville aerated pile method to local situations. p. 83-93. In Proceedings of 2nd Conf. on Scientific Res. in the National Parks, Vol. 3. National Park Service, Washington.

Singh, A. 1975. Use of organic materials and green manures as fertilizers in developing countries. p. 19-30. In Organic materials as fertilizers. Soils Bull. no. 27, Food and Agricultural Organization, Rome.

Singh, R. S., and H. Ram. 1977. Effect of organic matter on the transformation of inorganic phosphorus in soils. J. Indian Soc. Soil Sci. 25:118-121.

Singh, S. 1957. Effect of organic manures and superphosphate singly and in combination on cotton and their residual effect on jowar (Sorghum vulgare). Indian J. Agron. 1:177-190.

Singley, M. E., M. Decker, and S. J. Toth. 1975. Composting of swine wastes. p. 492-495. In Managing livestock wastes. Proc. 3rd Int. Symp. on Livestock wastes. Am. Soc. Agric. Eng., St. Joseph, Mich.

Spohn, E. 1969. How ripe is compost. Compost Sci. 10:24-26.

Steel, R. G. D., and J. H. Torrie. 1960. Principles and procedures of statistics with special reference to the biological sciences. McGraw-Hill Book Co., Inc., New York.

Stewart, B. A., and B. D. Meek. 1977. Soluble salt considerations with waste application. p. 219-234. In L. F. Elliott and F. J. Stevenson (eds.) Soils for management of organic wastes and wastewaters. Soil Sci. Soc. Am., Madison.

Stout, B. A., C. A. Myers, A. Huran, and L. W. Faidley. 1979. Energy for world agriculture. Food and Agricultural Organization, Rome.

Strom, P. F., M. L. Morris, and M. S. Finstein. 1980. Leaf composting through appropriate low-level technology. Compost Sci. Land Util. Nov/Dec, 44-48.

Sullivan, B. J. 1975. Estudio sobre la producción de abono orgánico a partir de deshechos y el aprovechamiento de los mismos por la municipalidad de San Carlos. Ministerio de Agricultura y Ganadería, Centro Agrícola Regional de la Zona Norte, San Carlos, Costa Rica.

Suzuki, M., K. Harada, and K. Kumada. 1975. Analysis of the rotting process of rice straw-calcium cyanamide mixture of physical fractionation. Soil Sci. Plant Nutr. 21:173-183.

Suzuki, M, and K. Kumada. 1976. Analysis of the rotting process of sawdust and barnyard manure. Soil Sci. Plant Nutr. 22:361-372.

Swellengrebel, N. H., and M. M. Sterman. 1961. Animal parasties in man. D. Van Nostrand Co., Inc., New York.

Swift, R. S., and A. M. Posner. 1972. Humification of plant materials. Soil Biol. Biochem. 4:171-181.

Taiganides, E. P. 1977. Composting of feedlot wastes. p. 241-251. In E. P. Taiganides (ed.) Animal wastes. Applied Science Publishers Ltd., London.

Tanner, C. C. 1968. Fertilizer demand and supply to the year 2000. Outlook on Agric. 5:235-240

Taylor, R. J. 1973. A further assessment of the potential hazard for calves allowed to graze pasture contaminated with Salmonella dublin in slurry. Brit. Vet. J. 129:354-357.

Taylor, R. J., and M. R. Burrows. 1971. The survival of Escherichia coli and Salmonella dublin in slurry on pastures and the infectivity of S. dublin for grazing calves. Brit. Vet. J. 127:536-542.

Thorne, C. E. 1913. Farm manures. Orange Judd Co., London

Tisdale, S. L., and W. L. Nelson. 1975. Soil fertility and fertilizers, 5th ed. Macmillan Publishing Co., Inc., New York.

Toth, S. J. 1973. Composting agricultural and industrial organic wastes. p. 172-184. In G. E. Inglett (ed.) Symposium: processing agricultural and municipal wastes. The Avi Publishing Co., Inc., Westport, Conn.

Travis, D. O., W. L. Powers, L. S. Murphy, and R. I. Lipper. 1971. Effect of feedlot lagoon water on some physical and chemical properties of soils. Soil Sci. Soc. Amer., Proc. 35:122-126.

Tsukada, T., S. Sugihara, and M. Deguchi. 1966. Nitrogenuous compounds and carboyhdrates in compost manure. Soil Sci. Plant Nutr. 12:127-129.

Turner, D. O. 1975. On-the-farm determination of animal waste disposal rates for crop production. p. 587-590. In Managing livestock wastes. Proc. 3rd Int. Symp. on Livestock Wastes. Am. Soc. Agric. Eng., St. Joseph, Mich.

United States Department of Agriculture. 1978. Improving soils with organic wastes. United States Department of Agriculture, Washington.

Vanderholm, D. H. 1975. Nutrient losses from livestock wastes during storage, treatment, and handling. p. 282-285. In Managing livestock wastes. Proc. 3rd Int. Symp. on Livestock Wastes. Am. Soc. Agric. Eng., St. Joseph, Mich.

VanVuren, J. P. J. 1948. Soil fertility and sewage. Dover Publications Inc., New York.

Vargas, R. (ed.). 1942. Scatología Mexicana. Materials excrementicias y secretoriales animales usados por los Mexicanos precolombianos y actuales. Biblioteca Aportación Histórica, Mexico City.

Velez-Romos, A., and L. Standifer. 1977. Effect of soil organic matter and moisture level on extractable manganese. J. Agric. Univ. Puerto Rico. 61:115-125.

Verma, S. S., and P. S. Lamba. 1963. Superphosphate adds to the efficiency of organic manures. Indian J. Agron. 7:231-235.

Vyas, M. K., and D. P. Motiramani. 1971. Effect of organic matter, silicates, and moisture levels on availability of phosphate. J. Indian Soc. Soil Sci. 19:39-43.

Wade, N. 1975. International agriculture research. Science 188: 585-588.

Waksman, S. A., and T. C. Cordon. 1939. Thermopilic decomposition of plant residues in composts by pure and mixed culture of microorganisms. Soil Sci. 47:217-223.

Waksman, S. A., T. C. Cordon, and N. Hulpoi. 1939. Influence of temperature upon the microbial population and decomposition processes in composts of stable manure. Soil Sci. 47:83-113.

Waksman, S. A., and F. C. Gerretson. 1931. Influence of temperature and moisture upon the nature and extent of decomposition of plant residues by microorganisms. Ecology 12:33-60.

Waksman, S. A., W. W. Umbreit, and T. C. Cordon. 1939. Thermophilic actinomycetes and fungi in soils and in composts. Soil Sci. 47:36-61.

Wallingford, G. W., L. S. Murphy, W. L. Powers, and H. L. Manges. 1975. Disposal of beef feedlot manure: Effects of residual and yearly application on corn and soil chemical properties. J. Environ. Qual. 4:526-531.

Wallingford, G. W., W. L. Powers, L. S. Murphy, and H. L. Menges. 1976. Salt accumulation in soil as a factor for determining application rates of beef feedlot manure and lagoon water. p. 713-726. In R. C. Loehr (ed.) Land as a waste management alternative. Proc. 1976 Cornell Agric. Waste Management Conf. Ann Arbor Science Publishers, Inc., Ann Arbor.

Walunjkar, W. G., and C. N. Acharya. 1955. Effect of compost prepared with superphospate on crop yield. J. Indian Soc. Soil Sci. 3:7-13.

White-Stevens, R. 1977. Perspectives on fertilizer use, residue utilization, and food production. p. 56-78. In R. C. Loehr (ed.) Food, fertilizer and agricultural residues. Proc. 1977 Cornell Agric. Waste Management Conf. Ann Arbor Science Publishers, Inc., Ann Arbor.

Willard, H. H., L. L. Merritt, and J. A. Dean. 1974. Instrumental methods of analysis. Van Nostrand Co., Inc., New York.

Willson, G. B. 1971. Composting dairy cow wastes. p. 163-166. In Livestock waste management and pollution abatement. Proc. Int. Symp. on Livestock Wastes. Am. Soc. Agric. Eng., St. Joseph, Mich.

Willson, G. B., and J. W. Hummel. 1975. Conservation of nitrogen in dairy manure during composting. p. 490-491. In Managing livestock wastes. Proc. 3rd Int. Symp. on livestock wastes. Am. Soc. Agric. Eng., St. Joseph, Mich.

Willson, G. G., J. F. Parr, E. Epstein, P. B. Marsh, R. L. Chaney, D. Colacicco, W. D. Burge, L. J. Sikora, C. F. Tester, and S. Hornick. 1980. Manual for composting sewage sludge by the Beltsville aerated-pile method. Office of Research and Development, United States Environmental Protection Agency, Cincinnati.

Winterhalder, S. J., R. F. Larsen, and E. P. Thomas. 1979. Dung as an essential resource in a highland Peruvian community. Human Ecol. 6:313-328.

Wolf, R. (ed.). 1977. Organic farming: Yesterday's and tomorrow's agriculture. Rodale Press, Emmaus, Penn.

Wood, R. A. 1963. The composition of manures produced in open and closed kholas in Nyasaland. Trop. Agric., Trin. 40:269-273.

Wortman, S. 1976. Food and agriculture. Sci. Am. 235:30-34.

Zucconi, F., M. Forte, A. Monaco, and M. Bertoldi, de. 1981. Biological evaluation of compost maturity. Biocycle July/Aug.: 27-29.

APPENDIX A
COMPOST

Table 44. Content of selected elements and dry matter in materials used in compost, CATIE, Group I (dry weight basis).

Material	% Dry Matter	% C	% N	% P_2O_5	% K_2O	% Ca
Corn Stover	68.38	48.13	1.12	0.37	1.56	0.37
Manure	17.33	35.80	1.44	0.87	1.36	1.72

Material	% Mg	% Cu	% Fe	% Mn	% Zn	% Al
Corn Stover	0.20	0.00	0.05	0.01	0.01	0.12
Manure	0.52	0.01	0.31	0.07	0.03	1.23

Table 45. Content of selected elements and dry matter in materials used in compost, Cariari (dry weight basis).

Material	% Dry Matter	% C	% N	% P_2O_5	% K_2O	% Ca
Corn Stover	74.35	41.15	0.96	0.35	0.76	1.43
Manure[a]	23.83	20.30	1.07	0.65	0.74	1.87
Manure[b]	32.83	15.98	1.33	0.78	1.78	2.45
Manure[c]	14.53	33.34	1.61	1.11	0.84	2.00

Material	% Mg	% Cu	% Fe	% Mn	% Zn	% Al
Corn Stover	0.28	-	0.10	-	0.01	0.13
Manure[a]	0.53	0.01	2.43	0.09	0.02	2.96
Manure[b]	0.60	0.01	1.30	0.04	0.02	0.79
Manure[c]	0.60	-	0.79	0.03	0.02	0.32

[a]Source: Dairy, Los Diamantes.

[b]Source: Corral, Los Diamantes.

[c]Source: Finca Lavillana

Table 46. Content of selected elements and dry matter in materials used in compost, La Pacífica (dry weight basis).

Material	% Dry Matter	% C	% N	% P_2O_5	% K_2O	% Ca
Sorghum Stover	58.77	38.52	0.71	0.20	2.31	1.41
Manure	36.44	25.81	1.50	0.53	1.23	3.73

Material	% Mg	% Cu	% Fe	% Mn	% Zn	% Al
Sorghum Stover	0.28	-	0.12	0.01	0.02	0.18
Manure	0.43	0.01	1.16	0.03	0.02	1.50

Table 47. Initial and final content of selected elements in compost, CATIE, Group I (dry weight basis).

Treatment	% P_2O_5		% K_2O		% Ca	
	Initial	Final	Initial	Final	Initial	Final
Unenriched	0.56	1.02	1.61	9.57	0.70	1.26
Enriched	1.33	1.11	2.12	7.08	1.05	1.29

Treatment	% Mg		% Cu		% Fe	
	Initial	Final	Initial	Final	Initial	Final
Unenriched	0130	0.28	-	0.98	0.12	15.94
Enriched	0.34	0.37	-	0.86	0.20	12.18

Treatment	% Mn		% Zn		% Al	
	Initial	Final	Initial	Final	Initial	Final
Unenriched	0.03	2.14	0.02	0.61	0.28	21.69
Enriched	0.04	1.95	0.02	0.47	0.80	15.76

Table 48. Concentration factor for selected elements in compost, CATIE, Group I.

Treatment	P_2O_5	K_2O	Ca	Mg	Cu	Fe	Mn	Zn	Al
Unenriched	1.82	5.94	1.80	0.93	98.00	132.83	71.33	30.50	77.46
Enriched	0.83	3.34	1.22	1.09	86.00	60.90	48.75	23.50	19.70

Table 49. Initial and final content of selected elements in compost, CATIE, Group II (dry weight basis).

Treatment	% P_2O_5 Initial	% P_2O_5 Final	% K_2O Initial	% K_2O Final	% Ca Initial	% Ca Final
Unenriched	0.58	1.78	1.70	2.04	0.62	1.42
Enriched	1.52	2.67	2.28	2.54	0.77	1.55

Treatment	% Mg Initial	% Mg Final	% Cu Initial	% Cu Final	% Fe Initial	% Fe Final
Unenriched	0.49	0.93	-	0.01	0.39	0.63
Enriched	0.54	0.71	0.01	0.01	0.56	0.62

Treatment	% Mn Initial	% Mn Final	% Zn Initial	% Zn Final	% Al Initial	% Al Final
Unenriched	0.05	0.14	0.02	0.03	0.89	3.52
Enriched	0.05	0.09	0.02	0.03	3.14	4.05

Table 50. Concentration factors for selected elements in compost, CATIE, Group II.

Treatment	P_2O_5	K_2O	Ca	Mg	Cu	Fe	Mn	Zn	Al
Unenriched	3.07	1.20	2.29	1.90	1.00	1.62	2.80	1.50	3.96
Enriched	1.76	1.11	2.01	1.31	1.00	1.11	1.80	1.50	1.30

Table 51. Initial and final content of selected elements in compost, Cariari (dry weight basis).

Treatment	% P_2O_5		% K_2O		% Ca	
	Initial	Final	Initial	Final	Initial	Final
Unenriched	0.72	0.70	0.96	0.87	1.95	2.07
Enriched	1.29	1.02	1.82	1.04	1.67	1.90

Treatment	% Mg		% Cu		% Fe	
	Initial	Final	Initial	Final	Initial	Final
Unenriched	0.48	0.62	-	0.01	0.90	2.20
Enriched	0.37	0.52	-	0.01	0.47	1.96

Treatment	% Mn		% Zn		% Al	
	Initial	Final	Initial	Final	Initial	Final
Unenriched	0.03	0.06	0.01	0.02	0.68	2.32
Enriched	-	0.05	-	0.02	0.32	2.24

Table 52. Concentration factors for selected elements in compost, Cariari.

Treatment	P_2O_5	K_2O	Ca	Mg	Cu	Fe	Mn	Zn	Al
Unenriched	0.97	0.91	1.06	1.29	1.00	2.44	2.00	2.00	3.41
Enriched	0.79	0.57	1.14	1.41	1.00	4.17	5.00	2.00	7.00

Table 53. Initial and final content of selected elements in compost, La Pacífica (dry weight basis).

Treatment	% P_2O_5		% K_2O		% Ca	
	Initial	Final	Initial	Final	Initial	Final
Unenriched	0.43	0.56	1.82	1.90	3.12	4.26
Enriched	0.91	1.56	2.27	2.15	2.82	4.40
Treatment	**% Mg**		**% Cu**		**% Fe**	
	Initial	Final	Initial	Final	Initial	Final
Unenriched	0.39	0.54	0.01	0.01	0.88	1.83
Enriched	0.37	0.45	0.01	0.01	0.77	1.87
Treatment	**% Mn**		**% Zn**		**% Al**	
	Initial	Final	Initial	Final	Initial	Final
Unenriched	0.02	0.05	0.02	0.02	1.15	2.20
Enriched	0.03	0.05	0.02	0.02	1.00	2.25

Table 54. Concentration factors for selected elements in compost, La Pacífica.

Treatment	P_2O_5	K_2O	Ca	Mg	Cu	Fe	Mn	Zn	Al
Unenriched	1.30	1.04	1.37	1.38	1.00	2.08	2.50	1.00	1.91
Enriched	1.71	0.95	1.56	1.22	1.00	2.43	1.67	1.00	2.25

Table 55. Selected characteristics of compost heaps, CATIE, Group I.

Treatment	Age of Heaps (In Weeks)	Moisture Content (%)	pH	% N	% C
Unenriched	0			1.34	45.41
Unenriched	2	75.00	7.63	1.14	25.79
Unenriched	4	79.71	6.66	1.34	29.92
Unenriched	5	71.36	6.90		
Unenriched	6	70.74	6.82		
Unenriched	8	75.32	7.25	1.09	19.47
Unenriched	9	79.49	7.59		
Unenriched	10	67.18	7.49		
Unenriched	12	70.35	6.90	1.05	16.20
Enriched	0	60.53	7.68	1.80	36.16
Enriched	1	63.02	6.81		
Enriched	2	65.39	7.72	0.55	15.07
Enriched	4	67.97	7.07	0.85	16.49
Enriched	5	69.11	7.64		
Enriched	6	69.16	7.57		
Enriched	8	69.42	7.39	0.91	15.74
Enriched	9	65.73	7.25		
Enriched	12	63.21	5.70	0.82	13.28

Table 56. Selected characteristics of compost heaps, CATIE, Group II.

Treatment	Age of Heaps (In Weeks)	Moisture Content (%)	pH	% N	% C
Unenriched	0	60.49	7.82	1.49	38.55
Unenriched	2	26.40	5.91	1.43	37.32
Unenriched	4	80.73	7.82	1.84	36.42
Unenriched	8	21.52	7.50	1.94	30.28
Unenriched	12	77.32	7.43	2.34	32.83
Enriched	0	27.33	7.57	1.23	36.04
Enriched	2	17.63	7.52	1.74	32.54
Enriched	8	63.11	7.51	1.84	31.72
Enriched	12	77.17	7.24	1.95	30.92

Table 57. Selected characteristics of compost heaps, Cariari.

Treatment	Age of Heaps (In Weeks)	Moisture Content (%)	pH	% N	% C
Unenriched	0	76.56	7.31	1.26	25.54
Unenriched	2		7.20	0.80	21.71
Unenriched	4	58.37	7.73	0.96	16.28
Unenriched	8	61.16	7.28	0.82	12.92
Unenriched	12	54.73	7.47	0.92	8.65
Enriched	0	80.25	7.05	1.86	31.37
Enriched	2		7.02	1.15	34.36
Enriched	4	49.89	6.82	1.12	25.60
Enriched	8	53.78	6.78	0.85	15.77
Enriched	12	60.64	6.24	1.21	15.88

Table 58. Selected characteristics of compost heaps, La Pacífica.

Treatment	Age of Heaps (In Weeks)	Moisture Content (%)	pH	% N	% C
Unenriched	0	47.44	6.85	1.30	29.14
Unenriched	2	23.41	6.90	0.87	25.17
Unenriched	4	50.31	7.36	1.47	26.18
Unenriched	8	62.22	7.70	1.30	17.02
Unenriched	12	50.00	7.44	1.48	17.99
Enriched	0	57.84	5.44	1.59	29.63
Enriched	2	37.33	7.25	1.06	25.10
Enriched	4	41.92	6.94	1.50	25.42
Enriched	8	65.72	7.42	1.59	19.40
Enriched	12	48.02	7.11	1.60	17.96

Table 59. Potash concentration, least significant difference between means, by site.

Unenriched

Cariari	La Pacífica	CATIE II	CATIE I
0.91	1.04	1.22	5.98

Enriched

Cariari	La Pacífica	CATIE II	CATIE I
0.57	0.95	1.33	3.35

Table 60. Potash concentration, least significant difference between means, by treatment.

CATIE I

Enriched	Unenriched
3.35	5.98

CATIE II

Unenriched	Enriched
1.22	1.33

La Pacífica

Enriched	Unenriched
0.94	1.04

Cariari

Unenriched	Enriched
0.57	0.91

Table 61. Aluminum concentration, least significant difference between means, by site.

Unenriched

La Pacífica	CATIE II	Cariari	CATIE I
1.94	4.10	4.26	77.56

Enriched

La Pacífica	CATIE II	Cariari	CATIE I
2.25	2.87	7.50	19.83

Table 62. Aluminum concentration, least significant difference between means, by treatment.

CATIE I

Enriched	Unenriched
19.83	77.56

CATIE II

Enriched	Unenriched
2.87	4.10

Cariari

Unenriched	Enriched
4.25	7.51

La Pacífica

Unenriched	Enriched
1.94	2.25

Table 63. Iron concentration, least significant difference between means, by site.

Unenriched

CATIE II	La Pacífica	Cariari	CATIE I
1.60	2.06	2.63	129.99

Enriched

CATIE II	La Pacífica	Cariari	CATIE I
1.15	2.43	4.29	60.86

Table 64. Iron concentration, least significant difference between means, by treatment.

CATIE I

Enriched	Unenriched
60.88	129.99

CATIE II

Enriched	Unenriched
1.15	1.60

La Pacífica

Unenriched	Enriched
2.06	2.43

Cariari

Unenriched	Enriched
2.63	4.29

Table 65. Zinc concentration, least significant difference between means, by site.

Unenriched	La Pacífica	Cariari	CATIE II	CATIE I
	1.00	1.67	2.83	40.67
Enriched	La Pacífica	Cariari	CATIE II	CATIE I
	1.17	1.67	2.00	12.48

Table 66. Zinc concentration, least significant difference between means, by treatment.

CATIE I	Enriched	Unenriched	CATIE II	Enriched	Unenriched
	12.48	40.67		2.00	2.83
Cariari	Unenriched	Enriched	La Pacífica	Unenriched	Enriched
	1.67	1.67		1.00	1.00

Table 67. Manganese concentration, least significant difference between means, by site.

Unenriched

La Pacífica	CATIE II	Cariari	CATIE I
2.50	3.08	4.89	71.33

Enriched

La Pacífica	CATIE II	Cariari	CATIE I
1.67	2.00	4.67	48.63

Table 68. Manganese concentration, least significant difference between means, by treatment.

CATIE I

Enriched	Unenriched
48.63	71.33

CATIE II

Enriched	Unenriched
2.00	3.08

Cariari

Enriched	Unenriched
4.67	4.89

La Pacífica

Enriched	Unenriched
1.67	2.50

Table 69. Final nitrogen content, least significant difference between means, by site.

Unenriched

Cariari	CATIE I	La Pacífica	CATIE II
0.92	1.05	1.48	2.34

Enriched

CATIE I	Cariari	La Pacífica	CATIE II
0.82	1.21	1.60	1.95

Table 70. Final nitrogen content, least significant difference between means, by treatment.

CATIE II

Enriched	Unenriched
1.95	2.34

La Pacífica

Unenriched	Enriched
1.48	1.60

Cariari

Unenriched	Enriched
0.92	1.21

CATIE I

Enriched	Unenriched
0.82	1.05

Table 71. Magnesium concentration, least significant difference between means, by site.

Unenriched

CATIE I	Cariari	La Pacífica	CATIE II
0.94	1.25	1.38	1.92

Enriched

CATIE I	La Pacífica	CATIE II	Cariari
1.07	1.23	1.36	1.40

Table 72. Magnesium concentration, least significant difference between means, by treatment.

CATIE II

Enriched	Unenriched
1.36	1.92

CATIE I

Unenriched	Enriched
0.94	1.07

Cariari

Unenriched	Enriched
1.25	1.40

La Pacífica

Enriched	Unenriched
1.23	1.38

Table 73. Calcium concentration, Duncan's multiple range test.

Cariari	La Pacífica	CATIE I	CATIE II
1.11	1.46	1.57	2.45

Table 74. Temperature in compost heap by depth and location, CATIE, Group I, Replicate I, Unenriched.

Depth (cm)	Corner	Corner	Center	Side	Side	Center	Corner	Corner
				Day 2				
0-25	38.5	37.0	25.5	51.0	53.5	53.0	49.0	-
25-50	42.0	47.0	36.0	46.5	49.5	49.5	35.0	-
50-75	40.0	40.0	41.0	42.0	37.0	40.0	38.0	-
75-100	33.0	35.0	40.5	35.0	35.0	35.0	35.0	-
				Day 9				
0-25	29.0	34.0	34.0	30.5	31.0	29.0	30.0	32.5
25-50	39.0	40.5	40.0	39.5	47.0	41.0	42.5	40.0
				Day 12				
0-25	45.5	37.0	36.5	43.5	48.0	39.6	46.0	52.0
25-50	41.0	38.0	40.5	40.5	45.0	43.5	45.0	41.0
				Day 13				
0-25	52.0	50.0	50.5	49.0	50.0	48.5	57.0	57.5
25-50	43.5	46.0	44.0	44.5	49.0	46.0	44.5	45.0
				Day 14				
0-25	40.0	44.0	44.5	41.0	42.5	40.0	48.0	44.5
25-50	49.0	45.5	43.5	44.5	47.0	46.0	44.0	44.0

Table 74.--Continued.

Depth (cm)	Corner	Corner	Center	Side	Side	Center	Corner	Corner
Day 15								
0-25	41.0	49.0	44.0	43.0	40.5	40.5	43.0	40.0
25-50	45.0	46.0	46.0	44.0	44.0	42.0	39.0	38.0
50-75	42.0	45.0	40.0	39.0	39.0	39.0	39.0	38.0
75-100	34.0	38.0	34.0	40.0	37.0	36.0	35.0	35.0
Day 16								
0-25	48.5	46.0	50.0	53.0	55.0	49.5	40.5	48.0
25-50	42.0	40.0	39.0	46.5	45.5	41.0	38.0	40.5
50-75	39.5	39.5	39.0	52.0	40.0	39.0	37.5	38.5
75-100	34.0	34.0	35.0	46.0	36.0	35.0	34.5	35.0
Day 17								
0-25	39.5	40.5	40.5	41.0	41.5	41.0	40.0	41.0
25-50	38.0	40.0	38.0	44.0	43.5	40.5	38.5	38.0
50-75	39.0	39.5	39.0	45.0	41.0	39.0	38.0	37.5
75-100	36.5	38.0	36.0	44.5	38.5	36.0	35.0	35.0
Day 18								
0-25	46.5	46.0	46.0	48.0	49.5	46.5	43.0	41.0
25-50	39.0	41.5	39.0	41.0	45.0	41.0	39.5	39.5
50-75	38.0	40.0	39.0	43.0	42.0	40.0	39.0	38.0
75-100	35.0	37.5	36.5	42.0	39.5	37.0	36.0	37.0

Table 74.--Continued.

Depth (cm)	Corner	Corner	Center	Side	Side	Center	Corner	Corner
Day 22								
0-25	47.0	58.0	52.0	50.0	53.0	58.0	45.0	50.0
25-50	44.0	40.0	35.0	40.0	40.0	40.0	39.0	37.0
50-75	40.0	35.0	37.0	48.0	38.0	40.0	37.0	36.0
75-100	30.0	35.0	34.0	40.0	-	38.0	33.0	34.0
Day 25								
0-25	45.0	44.0	46.5	44.5	45.0	45.0	50.0	52.5
25-50	43.5	45.5	41.0	45.5	42.5	44.5	41.5	42.0
50-75	38.5	39.0	39.0	36.0	40.5	40.5	38.0	38.0
75-100	34.0	35.0	34.5	42.0	36.0	36.5	34.0	34.0
Day 28								
0-25	54.0	46.5	57.0	54.5	53.0	52.0	49.0	49.0
25-50	42.5	41.5	43.0	41.5	48.0	45.5	44.5	40.5
50-75	39.0	40.5	39.0	44.0	41.0	40.0	36.0	36.0
75-100	34.0	36.0	37.0	40.5	37.5	36.0	33.0	34.0
Day 31								
0-25	46.0	44.0	52.0	45.5	48.0	45.5	48.0	50.0
25-50	41.5	39.0	42.0	41.0	41.0	41.5	39.5	40.0
50-75	38.0	36.0	41.0	39.5	36.5	38.0	36.5	34.0
75-100	35.0	32.0	35.0	35.5	35.0	35.0	35.0	33.0

Table 74.--Continued.

Depth (cm)	Corner	Corner	Center	Side	Side	Center	Corner	Corner
				Day 34				
0-25	41.0	42.0	42.5	56.0	59.0	44.0	43.0	51.0
25-50	42.0	38.5	41.0	51.0	51.5	40.0	38.0	37.5
50-75	35.5	36.0	36.0	43.0	38.0	34.5	33.0	33.0
75-100	32.0	35.0	-	-	-	-	-	-
				Day 36				
0-25	43.5	43.5	45.5	50.0	43.5	43.5	42.0	45.0
25-50	46.0	43.0	45.5	56.5	47.5	43.5	40.0	40.5
50-75	31.5	38.0	36.0	43.0	36.0	35.5	33.5	34.5
				Day 37				
0-25	42.5	39.0	47.0	43.0	49.0	45.0	42.0	43.0
25-50	45.5	41.5	47.0	55.5	50.0	47.0	40.5	40.0
50-75	32.0	35.0	38.0	40.0	40.0	38.0	37.0	35.0
				Day 38				
0-25	42.5	38.0	45.0	55.0	44.0	47.0	43.0	40.0
25-50	45.5	41.5	45.0	57.0	50.0	46.0	42.0	40.0
50-75	32.0	34.0	37.0	42.0	41.0	37.0	34.0	33.0
				Day 39				
0-25	35.0	34.5	35.0	49.0	42.0	41.0	38.0	40.0
25-50	37.0	37.0	41.0	52.5	45.0	45.0	40.5	40.0
50-75	30.5	34.0	35.5	39.0	38.0	36.5	34.5	34.0

Table 74.--Continued.

Depth (cm)	Corner	Corner	Center	Side	Side	Center	Corner	Corner
Day 42								
0-25	36.5	32.0	34.0	42.0	40.0	38.0	33.5	30.0
25-50	38.0	34.0	38.0	50.0	40.0	40.0	32.0	32.0
50-75	33.0	33.0	35.0	39.0	36.0	35.0	32.0	33.5
Day 44								
0-25	45.0	38.0	37.5	46.5	47.0	37.5	41.5	35.0
25-50	37.0	34.5	37.0	47.0	42.0	37.5	33.0	32.5
50-75	33.0	32.5	34.0	37.0	35.0	35.0	32.0	32.0
Day 47								
0-25	35.0	33.0	38.0	43.0	42.0	40.5	36.0	42.0
25-50	35.0	32.0	37.5	45.0	42.0	38.0	35.0	37.0
50-75	30.0	31.0	33.5	37.0	36.0	34.5	31.5	32.5
Day 50								
0-25	40.0	35.0	43.5	43.5	48.0	46.0	41.5	42.5
25-50	35.0	35.0	38.0	38.5	40.0	38.0	35.0	36.0
50-75	34.5	31.5	34.0	34.5	34.5	34.5	32.0	31.5
Day 53								
0-25	34.5	31.0	36.0	39.5	37.5	35.0	32.0	33.5
25-50	33.0	30.5	33.0	35.0	36.0	34.0	30.5	31.5
50-75	33.5	32.0	33.0	33.0	34.5	33.5	31.0	31.0

Table 74.--Continued.

Depth (cm)	Corner	Corner	Center	Side	Side	Center	Corner	Corner
				Day 56				
0-25	39.0	32.5	40.0	42.5	51.0	41.0	39.0	40.5
25-50	34.5	32.0	36.5	42.0	40.0	37.5	34.0	35.0
50-75	32.0	31.0	33.5	34.5	34.5	34.0	32.0	31.0
				Day 60				
0-25	35.0	34.0	41.0	44.0	43.0	44.0	43.5	46.0
25-50	32.0	33.0	34.0	38.5	40.5	37.5	35.5	37.0
50-75	30.0	30.5	31.0	33.5	34.5	34.0	32.5	31.5
				Day 62				
0-25	30.0	33.0	31.0	31.0	34.0	34.5	29.0	32.0
25-50	34.0	36.0	32.5	33.0	35.0	35.5	32.0	34.0
50-75	32.0	31.0	35.0	33.0	35.0	32.0	30.0	34.0
				Day 63				
0-25	35.0	37.0	33.0	33.0	35.0	33.5	30.0	32.0
25-50	37.0	38.5	32.0	33.0	34.0	35.0	30.5	31.0
50-75	32.0	33.5	33.0	35.0	35.0	33.0	30.0	31.0
				Day 64				
0-25	33.0	39.0	34.5	35.0	36.0	39.0	33.0	33.0
25-50	36.0	41.5	32.0	34.0	34.0	38.0	31.0	33.0
50-75	34.0	36.0	32.0	32.0	35.0	32.0	30.0	-

Table 74.--Continued.

Depth (cm)	Corner	Corner	Center	Side	Side	Center	Corner	Corner
Day 65								
0-25	35.0	35.0	35.0	40.0	40.0	42.0	34.5	34.0
25-50	37.0	42.0	34.0	36.0	35.0	40.0	33.0	33.0
50-75	36.0	37.0	34.0	34.0	35.0	34.0	32.0	32.0
Day 66								
0-25	35.0	30.5	35.0	37.0	34.0	41.0	35.0	34.0
25-50	39.5	36.0	33.0	33.0	33.0	40.0	32.5	33.0
50-75	29.5	32.0	32.0	-	32.0	33.0	31.0	31.0
Day 67								
0-25	30.0	32.5	34.0	34.0	33.0	38.0	33.0	32.0
25-50	35.5	36.5	32.0	33.5	31.5	37.5	32.0	32.5
50-75	29.0	31.0	32.0	32.0	31.0	33.0	31.0	31.0
Day 69								
0-25	32.5	33.0	35.0	32.0	31.5	34.0	30.0	29.5
25-50	35.0	36.0	32.0	31.5	31.0	35.5	30.5	32.0
50-75	32.0	31.5	32.0	32.0	31.5	32.5	31.0	31.0
Day 72								
0-25	32.0	29.0	32.0	34.0	32.0	37.0	33.0	32.5
25-50	36.0	30.5	31.0	31.0	30.0	38.0	32.5	32.5
50-75	30.0	33.0	32.0	31.0	31.5	33.0	30.0	30.0

Table 74.--Continued.

Depth (cm)	Corner	Corner	Center	Side	Side	Center	Corner	Corner
Day 75								
0-25	36.0	26.0	33.0	33.5	32.5	36.0	33.0	32.5
25-50	31.5	29.5	30.5	30.5	30.0	38.5	31.0	31.5
50-75	29.5	30.5	30.5	30.5	30.0	32.0	30.5	30.5
Day 78								
0-25	30.0	28.5	31.5	33.5	31.0	36.5	33.5	32.0
25-50	36.5	30.5	32.5	32.5	31.5	40.0	33.5	33.5
50-75	30.0	30.0	31.5	30.5	30.0	32.5	33.0	32.5
Day 81								
0-25	30.0	28.0	33.5	37.0	28.0	41.0	31.5	32.5
25-50	34.5	29.5	31.0	34.0	28.0	38.5	30.0	30.0
50-75	30.0	30.0	31.0	31.0	30.5	33.0	31.0	31.0
Day 84								
0-25	28.5	25.0	36.0	42.0	32.0	43.5	38.0	37.0
25-50	32.0	26.5	31.0	31.0	28.0	38.0	30.0	31.0
50-75	32.0	30.0	31.0	30.0	30.0	32.0	31.0	31.0
Day 88								
0-25	27.0	26.0	26.5	28.5	27.5	30.0	29.0	26.0
25-50	32.5	27.5	30.0	30.0	28.0	35.0	31.0	30.0
50-75	30.0	30.0	31.0	30.0	30.0	33.0	30.0	31.0

Table 74.--Continued.

Depth (cm)	Corner	Corner	Center	Side	Side	Center	Corner	Corner
Day 93								
0-25	26.0	26.0	35.0	35.0	33.0	38.0	34.0	32.5
25-50	29.0	27.0	32.5	32.0	31.0	38.0	31.0	30.0
50-75	29.0	30.0	30.5	30.0	30.0	32.0	30.0	30.0
Day 97								
0-25	23.0	23.5	25.0	25.0	25.0	26.0	23.0	23.5
25-50	28.0	25.5	27.0	26.5	26.0	30.0	26.0	25.5
50-75	28.0	28.5	30.0	29.5	30.0	31.0	30.0	30.0
Day 101								
0-25	20.5	20.5	22.0	23.0	22.5	24.5	22.5	21.0
25-50	25.5	24.0	25.0	25.0	24.0	29.0	24.0	24.0
50-75	27.0	28.0	29.0	28.5	28.5	30.0	23.0	29.0
Day 102								
0-25	24.5	22.0	28.5	31.0	28.5	29.0	28.0	29.0
25-50	27.0	23.5	29.5	31.0	29.0	28.0	28.0	28.5
50-75	27.0	27.0	28.5	28.5	28.5	30.5	28.5	29.0
Day 106								
0-25	22.0	23.0	24.0	24.0	25.0	25.0	22.5	23.0
25-50	26.0	24.0	27.0	26.5	26.5	30.0	26.0	26.0
50-75	26.5	27.0	29.0	28.0	28.5	30.0	28.5	29.0

Table 75.--Continued.

Depth (cm)	Corner	Corner	Center	Side	Side	Center	Corner	Corner
Day 8								
0-25	39.0	40.0	52.5	46.5	45.0	44.0	40.0	44.0
25-50	38.0	38.5	40.0	38.0	39.5	41.0	38.5	40.0
50-75	35.5	37.0	38.0	36.5	38.0	38.0	36.0	37.0
75-100	32.5	33.0	34.0	34.0	35.0	35.0	33.5	34.0
Day 9								
0-25	40.5	39.5	41.5	42.0	38.5	43.0	36.0	39.0
25-50	39.5	39.0	40.0	38.0	39.0	38.0	38.5	37.0
50-75	38.0	38.0	38.5	38.5	39.0	38.0	38.0	38.0
75-100	35.5	35.0	36.0	36.0	37.0	37.0	35.0	35.0
Day 10								
0-25	42.0	39.0	38.0	47.0	46.0	45.5	41.0	44.0
25-50	38.5	38.0	39.0	38.0	38.0	40.0	38.0	37.5
50-75	37.5	37.5	38.5	37.0	36.5	39.0	36.0	37.5
75-100	35.5	35.0	36.0	35.0	36.0	36.5	34.0	35.0
Day 14								
0-25	44.0	43.0	49.0	45.0	41.0	41.0	44.0	51.5
25-50	38.0	38.0	38.0	38.0	38.0	38.0	38.0	37.0
50-75	36.0	36.0	37.0	35.0	36.0	36.0	36.0	35.0
75-100	33.0	32.0	35.0	32.0	34.0	33.5	33.0	34.0

Table 75.--Continued.

Depth (cm)	Corner	Corner	Center	Side	Side	Center	Corner	Corner
				Day 17				
0-25	45.0	44.0	46.5	44.5	45.0	45.0	50.0	52.5
25-50	43.5	45.5	41.0	45.5	42.5	44.5	41.5	42.0
50-75	38.5	39.0	39.0	36.0	40.5	40.5	38.0	38.0
75-100	34.0	35.0	34.5	42.0	36.0	36.5	34.0	34.0
				Day 20				
0-25	46.5	39.5	51.5	50.0	45.5	47.0	50.0	47.0
25-50	40.0	40.0	47.0	37.0	38.5	41.0	41.0	40.0
50-75	36.0	34.5	38.0	37.0	36.0	37.0	35.0	35.0
75-100	33.0	34.0	34.0	34.0	33.5	34.0	34.0	42.5
				Day 23				
0-25	40.0	40.5	52.5	47.5	42.5	45.0	42.0	47.0
25-50	42.5	38.5	40.5	39.0	37.0	39.5	37.0	37.5
50-75	36.0	34.5	35.0	35.5	37.5	37.0	35.0	34.0
75-100	33.5	33.5	34.0	33.5	34.0	34.0	32.0	33.0
				Day 26				
0-25	40.0	38.0	45.0	42.5	42.0	45.0	42.5	47.5
25-50	41.0	39.5	39.0	36.0	37.0	39.5	39.0	39.0
50-75	34.5	34.5	36.0	36.5	34.5	34.5	35.5	34.0
75-100	32.0	33.0	33.5	33.5	33.0	34.5	33.5	32.5

Table 75.--Continued.

Depth (cm)	Corner	Corner	Center	Side	Side	Center	Corner	Corner
				Day 29				
0-25	39.0	37.0	45.0	46.0	44.0	46.0	43.0	43.0
25-50	44.0	40.0	47.0	46.5	39.0	42.0	43.0	42.0
50-75	34.5	36.0	36.5	40.5	36.0	35.5	36.0	36.0
75-100	33.0	35.0	34.0	-	34.5	34.0	34.0	33.0
				Day 34				
0-25	34.0	35.0	36.5	39.5	39.0	39.0	35.0	35.0
25-50	35.0	36.0	35.0	39.0	39.0	36.5	32.0	33.5
50-75	33.0	34.5	34.5	34.5	33.5	34.5	32.5	32.0
75-100	32.0	33.0	33.5	33.5	32.0	32.5	31.0	31.0
				Day 35				
0-25	33.5	35.0	37.0	44.0	46.5	41.0	34.5	42.5
25-50	36.0	38.0	38.0	41.5	43.0	38.0	32.5	35.5
50-75	31.5	33.0	33.5	34.5	34.0	33.5	32.5	32.0
75-100	31.0	33.0	33.0	34.0	33.0	33.0	31.0	31.0
				Day 36				
0-25	34.5	41.5	44.5	40.0	47.0	40.0	43.0	39.0
25-50	34.5	39.0	36.0	40.0	43.0	37.5	32.0	34.5
50-75	36.0	34.0	35.0	36.5	35.0	35.0	33.5	32.5
75-100	33.5	33.0	34.5	36.0	33.0	34.0	32.5	32.0

Table 75.--Continued.

Depth (cm)	Corner	Corner	Center	Side	Side	Center	Corner	Corner
				Day 37				
0-25	30.0	40.0	36.5	44.0	45.5	42.5	37.0	40.0
25-50	33.5	39.0	37.0	45.0	43.5	40.0	35.0	35.0
50-75	29.0	32.0	34.0	38.5	38.0	36.5	34.0	34.0
75-100	30.0	33.0	33.5	38.0	36.5	34.5	-	33.0
				Day 38				
0-25	35.0	40.0	32.5	35.5	35.0	37.5	32.0	36.0
25-50	35.0	37.0	36.0	44.0	43.0	38.0	32.0	35.0
50-75	33.0	33.0	33.5	39.5	36.0	35.0	32.0	32.0
75-100	31.0	32.0	33.5	37.0	35.0	34.5	32.0	32.0
				Day 41				
0-25	37.0	33.0	34.5	40.5	37.0	37.0	33.0	34.0
25-50	37.0	31.5	31.5	38.5	37.0	35.0	32.0	30.0
50-75	31.5	31.5	33.0	35.5	34.0	33.5	29.5	30.0
75-100	30.0	30.0	32.0	-	-	-	-	-
				Day 44				
0-25	29.5	30.0	33.0	42.0	45.0	35.5	31.0	34.0
25-50	29.5	30.0	30.5	36.0	37.5	34.0	27.5	30.5
50-75	30.0	30.0	31.0	34.0	33.5	33.0	29.5	30.0

Table 75.--Continued.

Depth (cm)	Corner	Corner	Center	Side	Side	Center	Corner	Corner
				Day 47				
0-25	32.0	34.0	38.0	45.0	42.5	42.5	40.0	37.0
25-50	31.0	31.0	34.0	46.0	37.5	38.0	34.0	33.5
50-75	30.5	30.5	31.0	37.0	34.0	34.0	30.5	30.5
				Day 51				
0-25	35.0	34.0	41.0	46.0	39.0	45.0	44.0	36.0
25-50	32.0	33.0	34.0	44.0	37.5	40.0	36.0	33.0
50-75	30.0	30.5	31.0	33.0	36.0	34.0	31.5	30.0
				Day 54				
0-25	25.0	26.5	29.5	32.5	33.0	34.0	28.0	28.0
25-50	25.5	27.0	29.0	34.0	32.0	34.0	27.0	28.0
50-75	26.0	28.0	31.0	33.0	34.0	34.0	30.0	30.0
				Day 57				
0-25	32.0	29.5	34.0	37.0	37.5	40.0	33.0	32.0
25-50	28.0	27.5	30.0	37.0	35.0	35.0	30.0	29.0
50-75	29.0	29.0	29.5	32.0	31.5	32.0	29.0	28.5
				Day 62				
0-25	30.0	33.5	30.5	30.5	28.5	32.0	33.5	33.0
25-50	30.0	38.5	31.0	32.5	28.0	33.5	35.5	35.0
50-75	30.5	34.0	31.5	32.0	31.0	31.5	29.0	29.0

Table 75.--Continued.

Depth (cm)	Corner	Corner	Center	Side	Side	Center	Corner	Corner
				Day 63				
0-25	27.0	30.0	26.5	30.0	29.0	33.0	30.5	28.0
25-50	30.0	37.0	29.0	32.5	28.0	35.0	32.0	33.0
50-75	28.0	31.0	31.0	32.0	31.0	31.0	30.0	29.0
				Day 64				
0-25	29.0	31.0	35.5	35.0	34.0	40.0	36.5	37.0
25-50	30.0	39.5	34.0	34.0	28.5	37.5	37.5	36.5
50-75	29.0	31.5	30.5	31.5	30.0	31.0	31.0	29.5
				Day 65				
0-25	26.5	31.5	37.5	36.5	39.0	43.0	36.5	36.0
25-50	30.5	40.5	35.5	36.0	32.0	39.5	38.5	37.5
50-75	30.0	36.5	33.5	33.0	31.0	31.5	33.5	30.5
				Day 66				
0-25	27.0	32.5	40.0	39.5	39.5	44.5	42.5	44.5
25-50	32.5	41.5	36.5	38.5	34.0	40.5	41.5	42.5
50-75	28.0	37.0	33.0	33.0	30.5	31.0	33.0	31.5
				Day 67				
0-25	31.0	36.0	42.0	43.5	35.0	43.5	44.5	42.5
25-50	33.5	43.0	35.5	38.0	32.0	38.5	42.0	41.5
50-75	33.0	38.0	33.0	33.0	30.0	31.0	31.0	31.5

Table 75.--Continued.

Depth (cm)	Corner	Corner	Center	Side	Side	Center	Corner	Corner
Day 68								
0-25	30.0	30.0	34.0	34.5	35.5	38.5	41.5	42.5
25-50	33.0	38.5	34.5	36.5	33.0	39.5	46.0	42.5
50-75	32.0	37.0	34.0	34.5	32.0	32.5	36.5	33.0
Day 71								
0-25	31.0	29.5	34.5	35.0	29.0	39.0	43.0	41.0
25-50	30.0	33.5	32.0	32.0	27.5	35.5	43.0	39.0
50-75	31.0	32.5	33.0	33.0	31.0	33.0	33.0	32.0
Day 74								
0-25	27.0	28.0	32.5	35.0	27.5	36.0	38.0	40.0
25-50	29.0	31.5	30.0	30.5	25.5	33.5	39.5	39.0
50-75	30.5	33.0	31.5	32.5	30.5	32.0	33.5	33.0
Day 78								
0-25	29.0	30.5	30.5	28.5	26.0	33.5	31.0	35.0
25-50	31.0	33.5	32.0	32.0	28.0	36.0	35.0	36.0
50-75	30.0	33.0	34.0	33.5	30.5	35.0	35.0	33.0
Day 83								
0-25	25.5	25.5	38.0	36.0	38.0	38.0	35.5	38.0
25-50	28.0	29.0	35.0	32.0	32.0	39.0	38.0	37.0
50-75	30.0	33.0	32.0	31.5	33.0	33.0	33.0	32.5

Table 75.--Continued.

Depth (cm)	Corner	Corner	Center	Side	Side	Center	Corner	Corner
				Day 87				
0-25	24.5	24.5	27.0	25.0	25.5	27.5	28.5	32.5
25-50	26.0	28.5	30.0	27.0	26.0	32.0	33.0	35.5
50-75	29.0	30.0	31.0	31.0	30.0	31.5	31.5	31.5
				Day 91				
0-25	20.0	22.5	26.5	24.0	23.5	25.0	25.0	27.0
25-50	24.0	27.0	28.5	26.5	25.5	29.0	32.0	33.0
50-75	28.5	29.5	30.0	29.5	29.0	30.0	30.5	30.0
				Day 95				
0-25	25.5	26.0	32.5	32.0	32.0	34.0	31.0	34.0
25-50	27.0	28.0	32.5	31.0	31.5	35.0	33.0	36.0
50-75	29.0	29.5	30.0	30.0	29.0	30.0	31.0	31.0
				Day 99				
0-25	24.5	26.0	26.0	28.0	26.0	23.5	26.0	27.5
25-50	27.0	28.0	28.0	29.5	28.0	28.0	28.5	30.5
50-75	29.0	28.5	29.0	29.0	28.0	29.0	29.0	29.0

Table 76. Temperature in compost heap by depth and location, CATIE, Group I, Replicate III, unenriched.

Depth (cm)	Corner	Corner	Center	Side	Side	Center	Corner	Corner
Day 1								
0-25	26.0	26.0	30.0	32.0	28.5	35.0	30.0	24.0
25-50	33.0	30.0	35.0	29.5	30.0	43.0	30.0	33.0
Day 4								
0-25	47.0	40.0	49.0	45.0	40.0	57.0	49.0	53.0
25-50	44.0	41.5	43.0	39.0	36.0	51.0	39.0	47.0
Day 5								
0-25	51.0	44.0	52.5	49.0	45.0	49.5	51.0	48.0
25-50	49.0	43.0	45.0	40.0	40.0	53.5	41.0	45.0
Day 6								
0-25	50.5	44.0	44.5	43.5	43.0	51.0	47.5	47.5
25-50	47.5	46.0	43.5	40.0	41.5	54.0	43.0	45.0
Day 7								
0-25	50.0	47.0	45.0	45.5	41.0	49.0	42.5	38.5
25-50	45.0	42.0	39.5	39.5	38.5	41.0	39.0	38.0
50-75	43.5	41.0	39.0	38.0	37.0	42.5	37.0	38.5
75-100	40.0	38.0	36.0	36.0	35.0	38.0	34.0	37.0

Table 76.--Continued.

Depth (cm)	Corner	Corner	Center	Side	Side	Center	Corner	Corner
				Day 8				
0-25	43.0	45.0	48.0	44.5	39.0	50.0	43.5	42.5
25-50	40.0	40.0	40.0	39.5	37.0	40.0	38.0	39.0
50-75	38.5	38.5	38.5	38.0	35.5	40.0	35.0	37.0
75-100	34.0	34.0	34.0	33.0	32.5	38.0	33.0	33.0
				Day 9				
0-25	47.0	40.0	40.5	36.5	36.0	41.5	38.0	38.0
25-50	41.0	39.0	38.0	38.5	37.0	39.0	38.0	37.5
50-75	40.0	38.0	38.5	38.5	36.5	40.0	37.0	37.0
75-100	36.5	36.5	37.0	36.0	35.0	38.0	36.5	35.5
				Day 10				
0-25	48.5	44.0	45.0	44.5	41.0	44.5	41.5	39.0
25-50	39.5	38.5	38.0	37.0	36.5	42.0	38.0	37.0
50-75	39.0	38.5	37.5	36.0	35.0	40.5	37.0	35.0
75-100	37.5	36.0	35.5	35.0	34.0	38.5	34.0	34.0
				Day 14				
0-25	53.5	48.0	57.5	40.0	43.0	60.0	41.0	50.0
25-50	39.0	37.0	39.0	37.5	36.0	42.0	36.0	37.0
50-75	35.5	36.0	38.0	35.0	34.5	38.5	33.5	35.0
75-100	33.0	34.0	34.5	32.5	32.0	36.0	33.0	32.0

Table 76.--Continued.

Depth (cm)	Corner	Corner	Center	Side	Side	Center	Corner	Corner
Day 17								
0-25	43.0	40.0	50.0	45.5	43.5	50.0	51.0	48.5
25-50	41.0	40.0	41.0	39.5	37.0	44.5	37.5	40.0
50-75	38.0	37.0	38.0	39.0	35.0	38.0	36.0	35.0
75-100	33.0	34.0	34.0	36.0	33.0	36.0	32.5	33.0
Day 20								
0-25	41.0	39.5	46.0	44.0	42.0	50.0	52.5	49.0
25-50	39.5	39.0	43.0	40.0	37.0	45.5	40.5	42.0
50-75	35.5	35.0	37.0	39.0	36.0	38.0	35.0	34.0
75-100	34.0	34.0	34.5	37.0	34.0	-	33.0	33.0
Day 23								
0-25	42.0	41.0	50.0	47.5	37.0	50.0	48.0	51.0
25-50	37.0	36.5	40.5	40.0	34.5	45.0	37.0	39.0
50-75	37.0	34.5	36.0	41.0	36.0	38.0	35.0	34.0
75-100	32.0	32.0	32.0	37.0	33.5	35.5	31.5	37.0
Day 26								
0-25	39.5	39.0	46.0	43.5	39.5	50.0	37.5	48.0
25-50	40.0	39.5	43.5	44.5	36.0	47.5	37.5	41.0
50-75	33.5	34.5	36.0	43.0	36.5	38.0	34.0	33.0
75-100	33.0	33.0	33.0	39.0	33.5	36.5	32.0	32.0

Table 76.--Continued.

Depth (cm)	Corner	Corner	Center	Side	Side	Center	Corner	Corner
				Day 29				
0-25	36.5	39.5	42.0	42.0	43.0	47.0	37.0	43.5
25-50	38.5	39.5	45.0	47.0	40.0	48.0	36.5	43.0
50-75	35.0	34.0	36.0	46.0	37.5	39.0	34.5	34.0
75-100	33.0	33.0	35.0	40.0	35.0	37.0	33.0	33.0
				Day 34				
0-25	33.5	34.0	36.0	42.5	42.0	43.0	34.5	34.0
25-50	33.5	34.0	37.0	42.0	40.5	40.0	34.0	36.0
50-75	34.0	33.0	34.5	36.0	35.0	36.5	32.5	33.0
75-100	31.0	32.0	33.0	33.5	33.0	35.0	31.0	31.5
				Day 35				
0-25	33.0	33.5	41.0	45.5	49.0	43.5	35.0	35.0
25-50	33.5	34.5	37.5	46.5	43.0	39.5	33.0	35.0
50-75	33.0	32.5	33.5	36.5	33.5	35.0	31.0	31.0
75-100	31.5	31.5	33.5	36.5	33.5	35.0	31.0	31.0
				Day 36				
0-25	33.5	33.5	42.0	50.0	51.5	48.0	45.5	46.0
25-50	32.0	35.0	37.5	51.0	42.0	42.5	34.0	38.0
50-75	32.5	32.5	34.0	38.0	37.0	37.0	32.0	32.0
75-100	32.0	32.0	33.0	38.0	35.5	35.5	31.0	31.0

Table 76.--Continued.

Depth (cm)	Corner	Corner	Center	Side	Side	Center	Corner	Corner
				Day 37				
0-25	33.5	36.5	39.0	40.0	40.0	40.0	38.0	35.5
25-50	32.0	34.0	39.0	40.0	41.5	42.0	35.0	39.0
50-75	32.5	31.5	33.0	40.5	41.0	39.5	35.0	-
75-100	33.0	31.5	33.0	40.0	-	39.0	-	-
				Day 38				
0-25	33.0	36.5	38.0	42.0	44.0	42.0	35.0	36.0
25-50	32.5	34.0	37.5	46.0	42.5	42.0	34.5	36.5
50-75	32.0	31.5	33.0	38.0	39.0	39.0	36.0	33.5
75-100	31.5	31.5	33.0	-	-	38.0	34.0	33.0
				Day 41				
0-25	33.0	30.0	42.0	40.0	38.0	54.0	43.5	42.0
25-50	30.5	30.0	35.0	45.5	40.0	43.5	37.0	35.5
50-75	31.0	30.0	32.0	36.5	37.0	36.0	30.0	40.0
				Day 44				
0-25	31.0	29.0	32.5	46.0	33.0	44.0	40.5	33.0
25-50	28.0	28.5	32.0	37.0	32.5	35.5	35.5	31.5
50-75	29.0	29.0	31.5	33.5	33.0	35.0	31.0	31.0
				Day 47				
0-25	32.0	30.0	38.0	40.0	39.0	42.5	44.5	43.0
25-50	30.5	29.0	36.0	40.0	38.5	42.5	37.0	36.0
50-75	30.0	29.5	31.5	34.0	33.0	34.5	31.0	30.5

Table 76.--Continued.

Depth (cm)	Corner	Corner	Center	Side	Side	Center	Corner	Corner
				Day 51				
0-25	30.0	31.0	38.0	43.0	46.5	53.0	44.0	42.0
25-50	30.0	30.0	35.0	41.0	41.5	47.0	37.0	35.0
50-75	30.0	30.0	31.0	34.5	34.0	36.0	30.0	30.0
				Day 54				
0-25	28.0	28.5	31.0	30.5	31.0	32.0	28.0	30.0
25-50	27.0	27.5	30.0	32.0	31.0	32.0	27.0	29.0
50-75	28.0	29.0	30.0	33.0	32.0	33.0	30.0	29.0
				Day 57				
0-25	28.5	29.0	34.0	37.5	32.0	41.0	31.0	30.0
25-50	28.0	28.5	32.5	37.0	31.0	39.5	29.0	29.0
50-75	28.0	28.0	30.0	31.5	31.0	33.0	29.0	29.0
				Day 62				
0-25	29.0	28.0	28.0	28.5	27.0	33.0	33.0	38.5
25-50	33.0	31.0	27.5	31.0	26.5	34.5	33.5	33.0
50-75	33.0	29.0	29.0	31.0	30.0	31.0	31.0	31.0
				Day 63				
0-25	29.0	29.0	27.5	27.5	27.0	29.5	29.0	30.5
25-50	34.0	32.0	28.0	30.0	27.0	35.0	33.0	33.0
50-75	30.0	30.5	30.0	30.0	30.0	30.5	30.0	30.5

Table 76.--Continued.

Depth (cm)	Corner	Corner	Center	Side	Side	Center	Corner	Corner
Day 64								
0-25	36.5	30.0	30.5	33.0	27.0	37.5	30.0	32.0
25-50	39.5	35.0	29.0	33.0	26.0	38.0	33.0	35.0
50-75	30.0	29.0	29.0	30.0	29.0	31.0	29.0	29.0
Day 65								
0-25	33.0	32.5	34.0	36.0	33.5	37.5	33.5	32.5
25-50	41.0	36.0	31.0	35.5	29.5	39.0	34.0	34.5
50-75	29.0	29.5	30.0	30.5	29.0	31.0	31.0	31.0
Day 66								
0-25	34.5	34.5	37.0	37.0	30.5	45.0	37.0	36.5
25-50	41.0	37.5	33.5	37.0	29.5	42.0	37.0	36.0
50-75	30.0	31.0	31.0	31.0	29.0	33.0	32.0	31.5
Day 67								
0-25	35.0	32.0	38.0	40.0	30.0	47.5	37.5	37.5
25-50	39.5	37.5	33.5	36.5	27.0	42.5	36.0	37.0
50-75	31.5	30.0	30.0	30.0	28.5	32.0	31.0	31.5
Day 68								
0-25	37.0	36.0	37.5	36.0	35.0	35.5	37.0	36.5
25-50	42.5	41.5	36.0	38.0	36.5	38.0	37.0	38.0
50-75	32.0	33.0	32.0	32.0	30.0	33.0	34.0	34.0

Table 76.--Continued.

Depth (cm)	Corner	Corner	Center	Side	Side	Center	Corner	Corner
				Day 71				
0-25	33.0	33.0	41.0	36.0	32.0	38.0	40.0	38.5
25-50	32.0	35.5	34.0	35.0	29.0	37.5	37.0	37.0
50-75	32.0	33.0	32.0	32.0	30.0	33.0	33.5	34.0
				Day 74				
0-25	32.0	38.0	34.5	38.0	31.0	33.0	36.0	37.0
25-50	37.5	41.0	31.5	34.5	27.0	33.0	35.0	36.0
50-75	32.0	33.0	32.0	31.5	30.0	32.0	32.0	32.0
				Day 78				
0-25	32.5	37.0	28.0	31.0	25.5	26.5	28.5	32.0
25-50	36.0	40.0	30.5	33.5	27.5	30.0	31.0	35.0
50-75	34.0	32.5	32.0	32.0	30.0	33.0	32.0	32.0
				Day 83				
0-25	28.0	31.0	32.0	36.0	35.5	32.0	36.0	45.0
25-50	31.0	33.0	30.0	34.0	31.5	32.0	33.0	36.0
50-75	32.0	31.0	31.0	31.0	30.0	31.0	30.0	31.5
				Day 87				
0-25	24.5	28.5	23.5	27.5	24.0	25.0	24.0	26.0
25-50	27.0	32.0	26.5	28.5	25.0	27.0	27.0	28.5
50-75	29.0	31.5	30.0	30.0	29.0	30.5	29.0	29.0

Table 76.--Continued

Depth (cm)	Corner	Corner	Center	Side	Side	Center	Corner	Corner
				Day 91				
0-25	28.0	29.5	30.0	32.5	27.5	28.5	31.0	31.0
25-50	30.0	29.5	30.0	32.5	28.0	29.0	31.0	32.0
50-75	29.0	29.0	29.0	29.0	28.5	29.0	29.0	29.0
				Day 95				
0-25	22.5	24.5	25.5	24.0	26.5	26.0	24.0	21.5
25-50	26.5	23.0	27.0	29.5	31.0	26.0	23.0	24.0
50-75	29.0	28.0	29.5	31.5	32.5	30.0	28.5	28.0
				Day 99				
0-25	24.5	26.0	26.0	28.0	26.0	23.5	26.0	27.5
25-50	27.0	28.0	28.0	29.5	28.0	28.0	28.5	30.5
50-75	29.0	28.5	29.0	29.0	28.0	29.0	29.0	29.0

Table 77. Temperature in Compost Heap, by Depth and Location, CATIE, Group I, Replicate I, Enriched.

Depth (cm)	Corner	Corner	Center	Side	Side	Center	Corner	Corner
Day 1								
0-25	37.5	34.0	43.5	41.5	36.0	43.0	41.0	37.0
25-50	38.5	36.0	36.5	41.5	39.0	42.0	35.5	33.0
50-75	33.5	35.0	36.0	37.0	33.5	39.5	37.0	32.5
75-100	33.0	36.0	36.0	33.5	30.5	35.5	35.5	30.5
Day 2								
0-25	28.0	27.0	34.0	34.5	30.0	30.0	31.0	30.0
25-50	38.0	27.5	44.5	42.5	39.0	43.0	35.5	37.5
50-75	37.5	38.0	42.0	40.5	38.5	36.0	36.0	35.0
75-100	37.0	36.0	40.0	38.0	36.0	37.0	34.0	32.0
Day 3								
0-25	33.0	31.0	33.0	28.0	32.0	34.0	28.0	27.0
25-50	42.0	40.0	44.0	32.0	40.0	44.0	32.5	35.0
50-75	33.0	37.0	41.5	37.0	34.0	34.0	35.0	35.0
75-100	34.0	35.0	41.0	36.0	37.5	36.0	33.5	34.0
Day 4								
0-25	34.0	33.0	38.0	40.0	35.5	40.0	35.0	34.5
25-50	39.0	37.0	43.0	44.0	40.0	46.0	37.0	35.0
50-75	34.5	37.0	41.0	41.0	40.0	41.0	37.0	35.0
75-100	36.0	35.0	40.0	38.0	39.0	38.0	35.5	34.0

Table 77.--Continued.

Depth (cm)	Corner	Corner	Center	Side	Side	Center	Corner	Corner
				Day 5				
0-25	32.5	31.5	34.0	33.0	35.5	32.5	29.0	29.0
25-50	38.5	38.5	42.5	42.0	42.5	42.5	32.5	24.0
50-75	37.5	36.5	39.0	39.5	40.0	40.5	39.0	35.0
75-100	35.5	34.5	38.5	37.0	38.5	39.5	35.0	33.0
				Day 6				
0-25	34.0	32.5	38.0	42.0	42.0	41.0	39.0	40.0
25-50	42.0	41.0	45.0	45.5	46.0	48.0	39.5	38.5
50-75	35.0	36.0	40.5	39.0	39.5	40.0	40.0	36.0
75-100	34.0	34.5	38.0	37.0	36.5	38.0	36.0	34.5
				Day 7				
0-25	33.5	33.5	46.5	46.0	46.0	47.0	47.0	38.0
25-50	36.0	38.0	44.0	43.5	45.0	46.0	39.0	36.5
50-75	36.5	36.0	38.0	39.0	38.0	40.5	36.0	36.0
75-100	35.0	35.5	39.0	38.0	36.5	38.0	35.0	34.5
				Day 10				
0-25	35.0	34.5	42.5	40.0	41.0	38.5	35.0	36.0
25-50	38.0	39.5	43.0	42.0	43.5	45.0	37.0	37.0
50-75	34.5	35.0	37.5	37.5	37.5	37.5	36.0	36.0
75-100	33.5	34.5	37.5	36.0	36.5	36.5	34.0	33.5

Table 77.--Continued

Depth (cm)	Corner	Corner	Center	Side	Side	Center	Corner	Corner
				Day 13				
0-25	32.0	31.0	44.5	43.5	40.0	46.5	46.5	39.5
25-50	36.0	36.0	44.0	45.0	43.0	47.0	41.5	38.5
50-75	33.0	34.0	38.0	38.0	38.0	37.5	35.5	34.0
75-100	33.0	33.5	36.5	37.5	36.0	36.5	33.5	33.0
				Day 16				
0-25	29.0	27.5	33.5	34.0	32.5	35.0	32.0	30.0
25-50	32.0	31.5	36.0	37.0	36.0	39.0	33.0	32.0
50-75	32.5	32.0	35.5	36.0	35.5	36.5	35.0	33.5
75-100	32.0	32.0	35.5	36.0	34.5	36.0	33.5	33.0
				Day 19				
0-25	35.0	32.5	46.0	46.5	41.5	48.0	46.0	36.0
25-50	35.0	34.0	42.0	42.0	40.0	44.0	37.0	35.0
50-75	38.5	36.0	35.0	37.0	35.5	38.0	35.0	34.0
75-100	-	-	-	35.0	35.0	35.5	33.5	34.0
				Day 23				
0-25	33.0	33.5	41.0	45.0	41.0	46.0	46.0	36.0
25-50	33.5	35.0	38.5	42.0	39.0	43.5	37.0	36.0
50-75	33.0	33.0	34.0	35.0	37.5	37.0	33.0	33.0
				Day 26				
0-25	27.0	28.5	30.0	31.5	32.0	35.0	30.5	31.0
25-50	27.0	30.0	30.0	32.0	33.0	36.5	31.0	30.5
50-75	30.0	31.0	32.0	32.0	33.0	35.0	32.0	32.0

Table 77.--Continued.

Depth (cm)	Corner	Corner	Center	Side	Side	Center	Corner	Corner
Day 29								
0-25	34.0	31.0	32.5	37.0	37.0	37.0	33.0	32.5
25-50	33.5	31.5	33.0	37.0	35.5	32.5	32.0	27.0
50-75	32.0	31.5	33.0	34.5	33.0	31.0	29.0	29.0
Day 34								
0-25	28.5	29.0	31.0	33.0	30.5	33.5	32.5	31.0
25-50	32.5	32.0	30.0	31.5	29.5	32.5	33.0	33.5
50-75	30.0	30.5	32.0	31.5	32.0	32.5	31.5	32.0
Day 35								
0-25	24.0	26.0	27.0	26.0	24.5	30.0	27.5	29.0
25-50	30.0	30.0	29.0	28.0	27.0	35.0	33.5	33.0
50-75	28.0	30.0	30.0	31.0	30.0	31.0	31.5	32.0
Day 36								
0-25	28.0	26.0	29.5	26.0	24.0	33.5	30.5	30.0
25-50	32.5	29.0	30.0	26.5	25.0	35.0	34.0	33.0
50-75	29.0	29.0	30.0	30.0	29.0	31.0	32.0	33.0
Day 37								
0-25	24.0	28.0	31.5	32.5	25.5	31.0	33.0	31.0
25-50	29.5	31.0	32.0	31.0	26.5	34.0	35.0	35.0
50-75	28.5	31.5	31.0	30.0	29.0	31.0	32.0	33.0

Table 77.--Continued.

Depth (cm)	Corner	Corner	Center	Side	Side	Center	Corner	Corner
Day 38								
0-25	27.5	27.5	36.0	33.0	27.5	36.5	34.0	31.5
25-50	33.5	33.0	34.5	30.5	27.0	36.5	36.5	36.0
50-75	30.5	32.0	31.5	30.0	29.0	31.5	32.0	33.0
Day 39								
0-25	32.0	30.0	36.5	34.0	28.5	39.0	38.0	36.0
25-50	35.0	33.5	35.5	29.5	27.5	35.0	37.0	37.5
50-75	33.0	33.5	31.5	30.0	29.0	31.0	32.0	33.0
Day 40								
0-25	32.0	30.0	32.0	33.5	29.0	37.5	34.0	31.5
25-50	35.0	35.5	35.0	31.5	29.5	37.5	36.0	37.5
50-75	34.5	33.0	33.0	30.0	30.0	32.5	33.5	35.0
Day 43								
0-25	30.0	28.5	33.5	28.5	27.0	38.5	31.0	31.0
25-50	35.0	32.0	33.0	26.5	26.5	37.0	31.5	32.0
50-75	31.0	33.0	33.0	31.0	30.0	32.0	32.5	34.0
Day 46								
0-25	29.0	27.0	40.0	38.0	28.0	38.0	34.5	32.0
25-50	32.0	30.0	38.0	29.0	26.0	35.0	32.0	31.0
50-75	32.0	32.0	32.0	31.0	30.0	32.0	33.0	33.0

Table 77.--Continued.

Depth (cm)	Corner	Corner	Center	Side	Side	Center	Corner	Corner
Day 50								
0-25	25.5	25.5	30.0	25.5	24.0	31.0	26.0	27.0
25-50	29.0	28.5	32.0	27.0	27.0	33.0	30.0	30.0
50-75	30.0	31.0	31.5	30.0	30.0	32.0	32.5	33.0
Day 55								
0-25	24.0	26.0	35.5	34.0	33.0	37.5	33.0	33.5
25-50	26.0	27.5	33.0	32.5	33.0	35.5	31.5	31.5
50-75	28.0	29.0	30.5	30.0	31.0	31.5	31.0	31.0
Day 62								
0-25	19.0	19.0	19.5	21.0	22.0	21.0	22.0	21.0
25-50	21.0	20.0	20.0	22.0	24.0	24.0	24.0	22.0
50-75	28.0	27.0	26.0	28.0	29.0	30.0	28.0	27.0
Day 63								
0-25	23.0	20.0	21.0	29.0	23.0	23.0	23.0	20.0
25-50	23.0	21.0	24.0	27.5	27.0	24.0	24.5	22.0
50-75	26.0	26.5	28.5	30.0	31.0	29.5	29.0	28.5
Day 64								
0-25	23.0	21.5	26.5	32.5	29.0	32.5	37.0	28.0
25-50	25.0	22.5	26.5	30.0	31.0	28.0	29.0	25.0
50-75	28.0	27.5	29.0	32.0	32.0	31.0	29.0	28.5

Table 77.--Continued.

Depth (cm)	Corner	Corner	Center	Side	Side	Center	Corner	Corner
				Day 65				
0-25	22.0	22.0	22.0	27.0	26.0	27.0	27.5	25.0
25-50	25.0	24.0	25.0	30.0	30.5	30.0	29.0	26.5
50-75	27.0	27.0	29.0	31.5	33.0	31.5	30.0	29.0
				Day 66				
0-25	24.0	23.5	26.0	32.5	30.0	32.5	34.0	29.0
25-50	25.5	24.0	27.5	38.0	31.5	32.5	31.5	29.0
50-75	27.5	27.0	28.5	31.5	33.0	31.0	29.5	29.0
				Day 70				
0-25	22.0	21.5	23.5	26.5	26.0	26.0	26.0	25.5
25-50	24.0	22.5	27.0	30.0	30.0	28.0	29.0	27.0
50-75	26.5	26.5	29.0	31.0	33.0	30.5	29.5	29.0
				Day 74				
0-25	21.0	21.0	22.0	22.0	21.5	23.0	22.5	22.0
25-50	23.0	23.0	23.0	22.0	23.0	22.5	23.0	24.0
50-75	27.0	28.0	28.0	30.0	29.0	30.0	30.0	31.0
				Day 77				
0-25	22.5	22.5	24.5	24.5	27.0	29.0	25.0	23.5
25-50	22.5	22.5	23.0	25.0	27.0	26.5	25.5	24.0
50-75	26.5	26.0	27.0	28.0	29.0	29.0	28.0	28.0

Table 77.--Continued.

Depth (cm)	Corner	Corner	Center	Side	Side	Center	Corner	Corner
Day 81								
0-25	21.0	22.0	22.0	20.5	23.0	23.0	21.0	20.0
25-50	21.5	23.0	23.0	21.0	25.0	25.0	23.0	23.0
50-75	27.0	27.0	26.0	26.0	27.0	28.0	26.0	26.0
Day 85								
0-25	21.5	21.0	24.0	26.0	23.5	27.0	27.0	27.0
25-50	22.5	21.5	25.0	26.0	24.5	26.0	27.0	26.0
50-75	24.0	25.0	27.0	27.5	28.0	28.0	28.0	28.0
Day 88								
0-25	21.0	22.0	21.5	22.0	23.0	22.0	22.5	22.0
25-50	22.0	24.0	22.0	23.0	24.0	22.0	23.0	23.0
50-75	27.0	27.0	27.0	26.0	26.0	27.0	27.0	26.5
Day 91								
0-25	19.0	19.0	18.0	20.0	19.0	20.0	21.0	19.0
25-50	20.5	22.0	20.0	22.0	23.0	23.0	24.0	20.0
50-75	28.0	29.0	27.0	29.0	29.5	28.0	30.0	28.0
Day 94								
0-25	20.0	20.0	20.0	20.0	22.0	22.0	22.0	20.0
25-50	21.0	22.0	21.0	21.0	22.0	24.0	23.0	22.0
50-75	26.0	26.0	27.0	26.0	29.0	28.0	28.0	27.0

Table 78. Temperature in Compost Heap, by Depth and Location, CATIE, Group I, Replicate II, Enriched.

Depth (cm)	Corner	Corner	Center	Side	Side	Center	Corner	Corner
				Day 1				
0-25	30.0	28.5	30.0	31.5	32.0	31.5	35.0	33.0
25-50	33.0	31.0	31.0	35.0	36.0	34.5	37.5	37.0
50-75	33.5	32.0	32.5	34.5	36.0	33.0	33.0	35.0
75-100	33.0	31.0	32.0	34.0	34.0	32.0	33.0	33.0
				Day 2				
0-25	26.5	30.5	27.5	31.5	29.0	28.0	32.5	27.0
25-50	40.0	37.5	40.0	40.0	38.0	39.0	39.0	39.0
50-75	35.5	37.0	41.0	39.0	38.5	39.0	37.5	36.0
75-100	35.0	35.0	38.0	37.5	36.5	38.5	36.0	34.0
				Day 3				
0-25	25.0	27.0	29.0	30.0	25.0	25.0	30.0	25.0
25-50	32.0	28.0	43.0	29.0	39.0	27.0	33.0	36.0
50-75	35.0	38.0	40.0	29.0	29.0	38.0	37.0	35.0
75-100	37.0	35.0	40.0	39.0	38.0	38.0	37.0	33.0
				Day 4				
0-25	36.5	27.5	39.0	39.0	35.5	35.5	36.0	35.0
25-50	42.0	42.5	45.0	43.0	40.5	40.0	37.5	36.0
50-75	36.0	38.0	41.0	41.0	40.5	40.0	37.5	35.5
75-100	34.5	37.0	41.5	39.0	39.0	38.5	35.0	33.0

Table 78.--Continued.

Depth (cm)	Corner	Corner	Center	Side	Side	Center	Corner	Corner
				Day 5				
0-25	31.0	33.5	41.0	42.0	39.0	37.0	32.0	32.0
25-50	38.0	41.0	45.0	42.5	41.0	40.0	36.5	36.0
50-75	36.5	38.5	40.0	38.5	39.0	39.0	36.0	34.0
75-100	36.0	36.0	38.5	38.0	37.0	37.5	35.0	33.0
				Day 6				
0-25	41.0	38.5	45.5	43.0	42.0	40.0	41.0	37.5
25-50	46.5	45.0	50.0	45.0	45.5	44.0	40.0	40.0
50-75	41.5	39.0	40.5	39.0	38.5	39.0	36.5	34.0
75-100	36.0	38.0	38.0	36.5	36.5	38.0	34.0	34.0
				Day 7				
0-25	42.0	41.0	47.0	39.0	31.0	47.0	45.5	42.0
25-50	44.5	44.5	47.5	43.5	42.0	43.0	40.0	39.0
50-75	37.0	38.5	39.0	39.5	38.0	39.0	36.5	33.5
75-100	35.0	36.0	39.5	37.5	37.0	38.5	34.5	32.5
				Day 10				
0-25	35.0	42.5	45.0	39.0	42.0	45.0	40.0	43.0
25-50	33.5	45.0	46.0	43.5	42.0	43.0	40.0	41.5
50-75	35.5	38.0	41.0	42.0	38.0	37.0	35.0	33.0
75-100	34.0	35.5	38.0	38.0	36.5	35.5	33.5	-

Table 78.--Continued.

Depth (cm)	Corner	Corner	Center	Side	Side	Center	Corner	Corner
				Day 13				
0-25	41.0	37.0	44.0	47.5	47.0	47.0	46.0	42.0
25-50	46.0	43.0	46.5	48.5	48.0	48.0	42.0	39.0
50-75	35.5	35.0	38.0	37.5	38.0	38.0	34.5	33.0
75-100	34.0	-	37.5	35.0	35.0	37.5	32.5	33.0
				Day 16				
0-25	33.5	33.0	36.0	40.0	40.5	42.5	36.0	34.0
25-50	37.0	35.5	40.0	42.0	41.0	39.0	36.0	33.0
50-75	34.5	35.0	36.5	36.0	36.0	35.5	36.0	32.0
75-100	34.0	34.5	36.5	35.0	35.0	34.5	35.0	-
				Day 19				
0-25	38.5	35.5	47.5	54.5	48.5	51.5	48.5	44.0
25-50	40.0	40.0	42.5	46.0	43.0	42.0	40.0	36.5
50-75	38.0	35.5	39.0	41.0	39.0	36.5	34.0	32.5
75-100	35.5	35.0	37.0	39.5	36.0	35.5	33.0	-
				Day 23				
0-25	39.5	37.0	41.5	52.5	47.0	46.0	45.0	35.0
25-50	41.0	39.0	40.0	46.0	43.5	40.0	40.0	34.0
50-75	34.0	34.0	35.5	39.5	35.0	35.0	33.0	32.0

Table 78.--Continued

Depth (cm)	Corner	Corner	Center	Side	Side	Center	Corner	Corner
				Day 26				
0-25	32.0	33.0	30.0	40.0	39.0	35.0	33.0	32.0
25-50	33.0	35.0	32.0	40.0	38.0	36.0	33.0	31.0
50-75	33.0	35.0	34.0	37.0	36.0	30.0	30.0	29.0
				Day 29				
0-25	34.0	31.0	32.5	37.0	37.0	37.0	33.0	32.5
25-50	33.5	31.5	33.0	37.0	35.5	32.5	32.0	27.0
50-75	32.0	31.5	33.0	34.5	33.0	31.0	29.0	28.0
				Day 32				
0-25	28.0	26.5	32.0	34.5	28.5	35.0	30.5	28.0
25-50	30.5	29.0	31.5	32.5	28.5	34.5	32.0	30.0
50-75	30.5	31.0	31.5	32.0	30.0	29.5	31.0	30.5
				Day 33				
0-25	24.5	25.0	29.0	28.5	26.5	32.5	26.0	24.0
25-50	30.0	32.0	32.0	30.0	27.0	35.0	29.0	27.5
50-75	30.0	31.0	30.5	30.0	28.5	29.5	28.5	28.0
				Day 34				
0-25	24.0	26.5	35.0	29.0	30.5	36.5	26.0	27.0
25-50	30.0	32.5	33.0	29.0	27.5	35.5	29.0	29.0
50-75	30.0	31.0	31.4	30.5	29.0	29.0	28.5	28.0

Table 78.--Continued.

Depth (cm)	Corner	Corner	Center	Side	Side	Center	Corner	Corner
				Day 35				
0-25	25.0	24.5	34.5	33.0	31.0	40.0	30.0	27.5
25-50	31.0	31.0	34.5	32.0	31.0	37.0	31.0	30.0
50-75	31.0	33.0	33.0	31.5	30.0	30.0	30.0	29.0
				Day 36				
0-25	25.5	27.5	35.0	32.5	30.0	38.0	31.5	32.0
25-50	32.5	32.5	34.5	30.0	28.5	36.0	32.5	33.0
50-75	30.5	33.0	33.0	30.0	28.0	29.5	29.0	29.0
				Day 37				
0-25	27.5	28.5	36.0	37.0	31.0	43.0	30.0	31.0
25-50	32.5	34.5	34.5	30.0	29.5	39.0	32.5	32.5
50-75	34.0	34.0	33.0	31.5	29.0	31.5	30.0	30.0
				Day 38				
0-25	29.0	29.0	37.0	32.5	33.0	40.0	32.0	32.5
25-50	32.0	33.5	36.5	31.0	30.0	37.5	32.0	31.0
50-75	32.5	33.0	33.5	31.0	28.0	29.0	29.5	28.0
				Day 41				
0-25	28.0	26.5	36.5	32.0	30.0	39.0	30.0	27.5
25-50	32.0	30.0	36.0	28.5	27.5	35.5	29.5	26.0
50-75	31.5	32.5	33.5	31.0	28.5	29.0	28.0	28.0

Table 78.--Continued

Depth (cm)	Corner	Corner	Center	Side	Side	Center	Corner	Corner
				Day 44				
0-25	26.5	25.0	40.0	32.5	28.5	35.0	30.0	27.0
25-50	31.0	27.5	35.0	28.0	25.5	33.0	25.5	25.5
50-75	31.0	32.5	33.0	31.0	28.0	28.0	27.0	27.5
				Day 48				
0-25	28.5	28.0	31.0	25.0	26.0	31.0	27.0	25.5
25-50	31.0	33.0	31.0	28.0	27.0	32.5	30.0	29.5
50-75	32.0	32.0	34.0	30.0	28.0	29.0	29.0	29.0
				Day 52				
0-25	25.0	25.0	32.5	28.0	31.0	33.5	33.5	31.0
25-50	26.0	27.0	33.0	26.0	29.0	33.0	32.5	30.0
50-75	30.5	30.0	31.0	29.0	28.0	29.0	29.0	29.0
				Day 59				
0-25	20.0	21.0	20.0	21.5	23.0	22.0	21.0	22.0
25-50	22.0	22.0	20.0	23.0	25.0	22.0	21.0	23.0
50-75	29.0	28.0	26.0	28.0	29.0	27.0	26.0	27.0
				Day 60				
0-25	21.0	20.0	23.0	23.5	22.0	23.0	24.0	21.5
25-50	23.0	22.0	25.0	26.0	25.0	24.0	23.5	23.5
50-75	26.5	27.0	28.5	28.5	29.0	27.5	27.0	27.0

Table 78.--Continued.

Depth (cm)	Corner	Corner	Center	Side	Side	Center	Corner	Corner
Day 61								
0-25	22.5	22.5	32.0	35.0	30.0	32.5	37.0	35.0
25-50	24.0	23.5	28.5	31.0	28.5	29.0	29.0	29.0
50-75	27.5	28.0	29.0	29.0	29.5	28.0	27.0	27.0
Day 63								
0-25	24.5	24.0	27.0	29.0	25.0	25.5	28.0	24.5
25-50	25.0	25.5	29.0	31.5	29.0	27.0	28.0	27.0
50-75	28.0	28.0	30.0	29.5	29.0	28.0	27.5	27.5
Day 64								
0-25	28.0	25.5	31.0	32.5	31.0	21.5	30.5	30.5
25-50	27.5	26.0	31.0	32.5	30.0	27.5	29.0	28.5
50-75	28.0	28.0	29.5	29.0	29.0	28.0	28.0	27.0
Day 68								
0-25	21.0	19.0	21.0	20.0	20.0	21.0	22.0	20.0
25-50	22.0	19.0	23.0	21.0	22.0	22.0	22.5	23.0
50-75	25.5	25.0	24.0	25.0	25.0	26.0	25.0	26.0
Day 72								
0-25	22.0	22.0	21.5	21.0	22.0	22.0	21.0	21.0
25-50	25.0	23.0	22.0	23.0	23.5	23.0	22.5	23.0
50-75	27.0	27.0	26.0	26.0	27.0	26.0	27.0	27.0

Table 78.--Continued.

Depth (cm)	Corner	Corner	Center	Side	Side	Center	Corner	Corner
				Day 75				
0-25	21.0	21.0	23.5	23.5	23.5	24.5	20.5	21.0
25-50	20.0	20.0	21.5	22.0	20.0	21.0	19.0	21.0
50-75	25.0	25.0	25.0	24.0	24.0	24.0	23.5	24.0
				Day 79				
0-25	-	-	-	20.0	22.0	20.0	-	-
25-50	-	-	-	21.0	23.0	20.0	-	-
50-75	26.0	26.0	25.0	25.0	25.0	25.0	25.0	26.0
				Day 83				
0-25	25.0	23.0	27.5	30.5	24.0	31.0	30.5	30.0
25-50	24.5	23.0	26.5	28.0	23.0	26.5	28.0	27.0
50-75	27.0	26.0	26.5	-	25.0	25.0	26.0	26.0
				Day 86				
0-25	19.8	21.0	21.5	22.0	23.0	25.0	23.0	23.0
25-50	22.0	23.0	24.0	23.5	23.0	26.0	22.0	24.0
50-75	30.0	30.5	29.0	30.0	29.0	31.0	28.0	29.0

Table 78.--Continued.

Depth (cm)	Corner	Corner	Center	Side	Side	Center	Corner	Corner
Day 89								
0-25	20.0	21.0	21.0	22.0	20.0	23.0	24.0	22.0
25-50	22.0	23.0	23.0	22.5	24.0	26.0	26.0	24.0
50-75	30.0	29.0	28.0	27.0	28.0	29.0	28.0	27.0
Day 93								
0-25	21.0	23.0	21.0	23.0	22.0	22.0	23.0	21.0
25-50	22.5	25.0	22.0	22.0	24.0	23.5	24.5	23.0
50-75	28.0	28.0	27.0	26.0	27.0	26.0	28.0	27.0

APPENDIX B
YIELD RESPONSE

Table 79. Grain Yield, La Pacífica, Duncan's Multiple Range Test, By Block

Block 5	Block 4	Block 3	Block 1	Block 2
533.11	578.22	800.37	926.39	991.67

Table 80. Grain Yield, La Pacífica, Duncan's Multiple Range Test, By Treatment.

Control	Chemical & Organic	Enriched Organic	Unenriched Organic	Chemical
432.44	655.83	796.67	810.00	1,104.44

Table 81. Grain Yield, Cariari, Duncan's Multiple Range Test, By Treatment.

Unenriched Organic	Control	Enriched Organic	Chemical	Chemical & Organic
1,011.67	1,136.00	1,543.78	1,759.78	2,026.89

Table 82. Grain Yield, Cariari, Duncan's Multiple Range Test, By Farm.

Farm 2	Farm 1	Farm 3
727.78	1,350.78	3,900.83

Table 83. Stover Yield, Cariari, Least Significant Difference Between Means, By Treatment.

Treatment	Farm		
Control	2 1,600.00	1 3,956.67	3 7,451.11
Chemical	1 4,258.33	3 5,500.00	2 5,732.78
Chemical & Organic	1 4,577.78	3 6,855.56	2 10,246.67
Unenriched Organic	2 3,172.22	1 5,446.67	
Enriched Organic	1 3,729.44	2 6,955.56	3 8,921.11

Table 84. Total Biomass, Cariari, Least Significant Difference Between Means, By Treatment.

Treatment	Farm		
Control	2 1,678.89	1 4,735.00	3 11,416.67
Chemical	1 5,847.22	2 6,712.78	3 9,701.11
Chemical & Organic	1 6,310.00	3 10,487.78	2 11,765.56
Unenriched Organic	2 3,480.56	1 7,161.67	
Enriched Organic	1 1,678.89	2 4,735.00	3 12,725.56

Table 85. Stover Yield, Carari, Least Significant Difference Between Means, By Treatment.

Farm	Treatment				
1	Enriched Organic 3,729.44	Control 3,956.67	Chemical 4,258.33	Chemical & Organic 4,557.78	Unenriched Organic 5,446.67
2	Control 1,600.00	Unenriched Organic 3,172.22	Chemical 5,732.78	Enriched Organic 6,955.56	Chemical & Organic 10,246.67
3	Chemical 5,500.00	Chemical & Organic 6,855.56	Control 7,451.11	Enriched Organic 8,921.11	

Table 86. Total Biomass, Cariari, Least Significant Difference Between Means, By Farm.

Farm	Treatment				
1	Enriched Organic 1,678.89	Control 4,735.00	Chemical 5,847.22	Chemical & Organic 6,310.00	Unenriched Organic 7,161.67
2	Control 1,678.89	Unenriched Organic 3,480.56	Enriched Organic 4,735.00	Chemical 6,712.78	Chemical & Organic 11,765.56
3	Chemical 9,701.11	Chemical & Organic 10,487.78	Control 11,416.67	Unenriched Organic 12,725.56	

APPENDIX C
SOILS DATA

Table 87. Soil pH Values, Turrialba.

Block	Treatment	Parcel	Days After Planting 0	2	45	90
I	Control	41	4.4	4.6	5.6	5.5
	Chemical	49	5.2	4.5	5.2	5.0
	Pure Organic	53	5.2	6.0	5.7	5.2
	Enriched Organic	57	4.9	5.2	5.1	5.9
	Organic + Chemical	45	5.1	4.5	4.9	5.5
II	Control	46	5.0	4.7	5.6	4.9
	Chemical	42	6.7	4.7	6.1	6.4
	Pure Organic	54	5.5	5.3	5.5	5.1
	Enriched Organic	50	5.6	4.9	5.2	5.7
	Organic + Chemical	58	5.2	5.5	5.4	5.8
III	Control	55	5.1	5.2	5.2	5.2
	Chemical	59	5.6	5.4	5.8	5.4
	Pure Organic	43	5.7	4.7	5.5	6.2
	Enriched Organic	47	5.6	5.0	5.2	5.8
	Organic + Chemical	51	5.0	4.8	5.0	6.1
IV	Control	60	4.8	4.6	5.3	5.9
	Chemical	52	5.3	5.1	5.0	5.4
	Pure Organic	56	4.7	4.9	5.3	5.4
	Enriched Organic	44	5.7	4.8	5.4	5.5
	Organic + Chemical	48	6.0	4.7	5.4	4.9

Table 88. Duncan's Multiple Range Test, Organic Matter Content of Soil, Cariari, by Treatment.

Unenriched Organic	Chemical	Enriched Organic	Chemical & Organic	Control
6.21	6.43	6.51	6.57	6.59

Table 89. Duncan's Multiple Range Test, Organic Matter Content of Soil, Cariari, by Sampling Date.

Day 2	Day 0	Day 45	Day 90
6.35	6.37	6.37	6.77

Table 90. Mean Organic Matter Content of Soil, CATIE, By Time and Treatment.

(n=8)

Days After Planting	Unenriched Organic (%)	Enriched Organic (%)	Combined Chemical & Organic (%)	Chemical (%)	Control (%)
	Fertilizer Treatment				
0	5.84	6.73	5.99	6.46	6.80
2	5.80	6.38	6.58	6.30	6.67
45	6.48	6.41	6.39	6.38	6.21
90	6.73	6.53	6.76	7.15	5.66

Table 91. Mean Organic Matter Content of Soil, Cariari, By Time and Treatment.

(n=12)

Days after Planting	Unenriched Organic (%)	Enriched Organic (%)	Combined Chemical & Organic (%)	Chemical (%)	Control (%)
	Fertilizer Treatment				
0	9.11	8.29	8.00	8.09	8.63
2	9.19	9.32	8.16	8.08	8.33
45	9.96	9.41	9.78	8.95	8.60
90	9.10	8.39	8.97	8.30	8.78

Table 92. Mean Organic Matter Content of Soil, La Pacífica, By Time and Treatment.

(n=10)

Days After Planting	Unenriched Organic (%)	Enriched Organic (%)	Combined Chemical & Organic (%)	Chemical (%)	Control (%)
	Fertilizer Treatment				
0	5.45	5.75	5.17	4.90	4.83
2	5.63	5.36	5.67	5.45	4.93
45	4.74	5.40	5.52	4.45	4.89
90	4.86	4.95	5.45	4.81	5.28

Table 93. Mean Plant Nutrient Content of Soil, CATIE, by Time and Treatment.

Treatment	Days After Planting	N(1) (%)	P(2) (ppm)	K(2) (ppm)	Ca(2) (ppm)	Mg(2) (ppm)	Mn(2) (ppm)	Fe(2) (ppm)	Zm(2) (ppm)	Cu(2) (ppm)
Unenriched Organic	0	0.25	0.55	145.56	1666	54.64	27.85	5.00	0.66	3.45
	2	0.25	0.85	162.08	1601	73.30	32.46	4.70	0.69	3.78
	45	0.27	10.75	125.98	2055	88.64	30.68	4.65	0.91	3.31
	90	0.27	1.35	82.28	1911	62.50	28.05	5.00	0.58	3.25
Enriched Organic	0	0.27	0.65	177.56	1979	74.64	35.85	4.00	0.76	3.61
	2	0.27	1.80	200.08	1433	117.80	45.51	5.55	0.66	4.05
	45	0.28	6.25	160.98	1630	129.14	40.88	5.50	0.93	3.94
	90	0.27	1.20	102.78	2291	83.50	34.85	3.40	0.72	3.37
Combined Chemical & Organic	0	0.27	0.70	158.56	2399	74.14	28.25	3.30	0.77	2.99
	2	0.27	2.80	244.58	1649	68.80	39.81	5.30	0.57	3.50
	45	0.28	12.50	170.48	2222	71.14	32.03	4.45	0.78	3.15
	90	0.26	1.75	122.28	1948	56.50	31.25	4.55	0.60	3.38
Chemical	0	0.26	0.75	152.06	1866	80.64	32.40	4.50	0.79	3.74
	2	0.26	1.65	213.08	1324	85.80	41.51	5.40	0.50	3.81
	45	0.28	17.50	180.98	1615	90.14	38.73	6.85	0.93	3.75
	90	0.26	1.95	122.28	1948	56.50	31.25	4.55	0.60	3.38
Control	0	0.27	1.05	157.56	1172	76.14	37.90	7.00	0.99	3.83
	2	0.28	0.95	170.58	1156	68.30	37.26	6.30	0.58	3.71
	45	0.28	3.30	106.98	1973	73.64	28.28	4.15	0.80	3.24
	90	0.27	1.00	139.28	1648	71.50	31.90	4.70	0.69	3.39

1 n=4
2 n-8

Table 94. Mean Plant Nutrient Content of Soil, Cariari, by Time and Treatment.

Treatment	Days After Planting	N[1] (%)	P[2] (ppm)	K[2] (ppm)	Ca[2] (ppm)	Mg[2] (ppm)	Mn[2] (ppm)	Fe[2] (ppm)	Zn[2] (ppm)	Cu[2] (ppm)
Unenriched Organic	0	0.63	1.53	253.97	1664	181.98	16.47	2.60	0.73	0.17
	2	0.56	0.50	254.23	1934	158.61	16.17	2.47	0.56	0.16
	45	0.67	0.33	213.34	1984	170.25	15.30	2.37	0.73	0.15
	90	0.57	0.47	190.01	1915	180.59	15.63	2.27	0.66	0.18
Enriched Organic	0	0.54	1.10	167.63	1507	144.98	15.43	2.87	0.53	0.18
	2	0.53	0.53	218.90	2094	160.61	14.87	3.17	0.53	0.19
	45	0.56	0.30	143.34	1677	155.92	16.00	2.67	0.61	0.18
	90	0.55	0.43	177.34	1381	147.25	14.47	2.93	0.53	0.20
Combined Chemical & Organic	0	0.54	1.47	221.97	1530	160.98	14.77	2.73	0.57	0.18
	2	0.57	1.03	372.23	1564	168.94	18.57	3.10	0.51	0.19
	45	0.68	0.40	161.34	1672	186.92	16.63	2.80	0.65	0.18
	90	0.54	0.90	196.67	1450	154.25	16.27	2.67	0.52	0.20
Chemical	0	0.50	0.87	200.97	1332	157.98	15.00	2.97	0.65	0.19
	2	0.55	1.16	274.70	1416	161.34	15.24	3.36	0.48	0.20
	45	0.54	0.37	140.01	1752	161.25	14.10	2.60	0.58	0.18
	90	0.56	0.53	178.67	1450	154.25	16.27	2.67	0.52	0.20
Control	0	0.57	1.20	252.30	1600	179.31	16.03	2.77	0.68	0.18
	2	0.48	0.30	178.23	1754	157.61	15.23	2.47	0.46	0.16
	45	0.64	0.37	186.34	1874	185.25	13.40	3.07	0.63	0.21
	90	0.52	0.30	171.67	1763	169.25	13.17	2.60	0.52	0.19

1 n=6
2 n=12

Table 95. Mean Plant Nutrient Content of Soil, La Pacífica, by Time and Treatment.

Treatment	Days After Planting	N[1] (%)	P[2] (ppm)	K[2] (ppm)	Ca[2] (ppm)	Mg[2] (ppm)	Mn[2] (ppm)	Fe[2] (ppm)	Zn[2] (ppm)	Cu[2] (ppm)
Unenriched Organic	0	0.15	6.72	314.60	3572	468.74	21.08	1.80	1.87	0.46
	2	0.25	8.64	378.12	3792	477.24	23.72	1.80	2.02	0.39
	45	0.15	4.48	331.34	3677	476.24	27.60	3.88	1.73	0.63
	90	0.15	2.28	268.74	3568	439.28	27.60	2.58	1.66	0.50
Enriched Organic	0	0.20	7.36	333.80	3728	499.54	23.64	2.16	1.88	0.47
	2	0.19	26.76	427.72	3636	470.44	24.88	2.04	2.20	0.40
	45	0.16	4.04	341.34	3729	485.84	26.60	3.44	1.94	0.64
	90	0.16	4.16	281.14	3820	439.28	26.76	2.28	1.65	0.45
Combined Chemical & Organic	0	0.17	5.12	283.40	3580	477.94	21.88	1.96	1.91	0.45
	2	0.17	19.72	395.32	3796	496.04	28.04	2.00	2.27	0.38
	45	0.18	4.92	276.14	3793	499.84	28.20	2.80	1.93	1.42
	90	0.18	1.92	239.14	3832	458.48	25.16	1.76	1.72	0.37
Chemical	0	0.17	6.24	297.40	3620	444.54	22.28	1.96	1.84	0.47
	2	0.28	10.65	367.72	3886	451.74	26.00	1.65	1.83	0.39
	45	0.15	3.20	328.14	3745	450.24	33.04	5.24	1.67	0.73
	90	0.16	2.16	239.14	3832	458.48	25.16	1.76	1.72	0.37
Control	0	0.15	6.40	351.00	3540	441.94	23.20	2.80	1.87	0.71
	2	0.16	1.88	354.92	3780	439.24	22.88	1.92	1.66	0.46
	45	0.15	1.80	275.74	3861	455.84	28.16	3.60	1.34	0.62
	90	0.17	1.96	303.94	3744	447.28	25.52	2.04	1.97	0.40

1 n=5
2 n=10

APPENDIX D
QUESTIONNAIRE

Nombre de Finquero ______________________ Localidad de la Finca ______________________
(Name of Farmer) (Location of Farm)

I. Boñiga (Manure)

A. Fuentes de Boñiga (Sources of Manure)

	Vacas de Leche en Produccion (Milk Cows in Production)	En Confinamiento (Confined) Chanchos (Pigs)	Aves (Birds)	Otros (Other)
Número de Animals (Number of Animals)	Promedio/Año (Average/Year) Dando Leche Ahora (Giving Milk Now) Promedio de Peso (Average Weight)			
Comida (Food) Pasto (Pasture) Tipo (Type)				
Pasto de Corte (Tall Grass Pasture) Tipo (Type) Kg/An/Dia (Kg/Animal/Day)				
Concentrado (Concentrate) Tipo (Type) % de Proteína (% Protein) Kg/An/Dia (Kg/Animal/Day)				
Melaza (Molasses) Kg/An/Dia (Kg/Animal/Day)				

Urea (Urea) Kg/An/Dia (Kg/Animal/Day)			
Rastrojo (Wastes) Tipe (Type) Fresco o Seco (Fresh or Dry) En qué época (Season) Kg/An/Dia (Kg/Animal/Day)			

B. Cantidad de Boñiga Disponible (Quantity of Manure Available)

1. De vacas (From cows)

Cuantas veces por dia ordeña? ________ (How many milkings per day?)

Cuanto tiempo están las vacas en el galerón de ordeño por ordeno? ________ (How long are the cows in the milking parlor per milking?)

Cuanto tiempo dura limpiando el galerón después de cada ordeño? ________ (How long do you spend cleaning the parlor after each milking?)

2. Otras Fuentes (Other Sources)

	(Pigs) Chanchos	(Birds) Aves	(Other) Otros
Cada cuanto limpia (How often do you clean??			
Kg de boñiga por limpieza (Kg of manure per cleaning?)			
Horas de trabajo por limpieza (Hours of work per cleaning?)			

II. Uso de Boñiga (Use of Manure)

A. Tipos de Usos (Types of Uses)

	(Cows) Vacas	(Hogs) Chanchos	(Fowl) Aves	(Other) Otros
La bota (Throw it away)				
La recoge y aplica (Collect and apply it)				
A todos los potreros (To all pastures)				
A los más cercanos (To the nearest only)				
A cultivos (To field crops)				
A hortilizas (To vegetables)				
La aplica por sanjas (Apply it by trench)				
A potreros (To pasture)				
A algo más (Other)				

B. Si no usa la boñiga, porque? (If you do not use the manure, why not?)

1. Gasta demasiado mano de obra recogerla _____ (Too much labor to collect it)
2. Cantidad insuficiente _____ (Insufficient quantity)
3. Demasiado difícil recogerla _____ (Too difficult to collect it)
4. Miedo de enfermedades _____ (Fear of illness)
5. Miedo de sembrar malezas _____ (Fear of weeds)
6. Falta de información sobre los usos posbiles _____ (Lack of information about possible uses)

7. Le resulta desagradable usarla _____ (Disagreeable to use it)

8. Otro ____ (Other)

C. Usos posibles como reemplazo de fertilizante químico (Possible uses to replace chemical fertilizer)

	Época de la Siembra (Planting Season)	Has. Sembradas (Hectares Planted)	Fertilizante Químico Aplicado (Chemical Fertilizer Applied)	
			Formula (Formula)	Cantidad/Ha. (Quantity/Ha)
Cultivos Anuales (Annual Crops)				
Cultivos Perennes (Perennial Crops)				
Hortilazas (Vegetables)				
Pasto (Tipos) [Pasture (Types)]				
Pasto de Corte (Tipos) [Tall Grass Pasture (Types)]				

III. Otras Cosas (Other)

1. Cuales son las posibles fuentes de matéria orgánica (que no tienen otro uso en la finca)?
   [What are the possible sources of organic material (that have no other use on the farm)]?

2. Tiene la finca una picadora? Si _____ No _____
   (Does the farm have a chipper?) (Yes) (No)

3. Considera que el uso del fertilizante orgánico es bueno?
   (Do you think the use of organic fertilizer is a good idea?)

4. Tendría interés en hacer fertilizante orgánico?
   (Would you be interested in making organic fertilizer?)

BIOGRAPHICAL SKETCH

Marilyn E. Swisher was born August 11, 1948, in Christopher, Illinois. Her undergraduate degree was earned at Eastern Illinois University in March, 1972, in geography. Greaduate degrees include an M.A. in geography, with a joint major in ecology, earned at Wayne State University in June, 1976, and the Ph.D. completed in geography with a minor in soil science at the University of Florida in May, 1982.

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Hugh Popenoe

Hugh Popenoe, Chairman
Professor of Geography

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

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I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

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This dissertation was submitted to the Graduate Faculty of the Department of Geography in the College of Liberal Arts and Sciences and to the Graduate Council, and was accepted as partial fulfillment of the requirements for the degree of Doctor of Philosophy.

May, 1982

Dean for Graduate Studies and Research